US ARMY
LABORATORY COMMAND

CONTRACT REPORT NUMBER 10-91
PREPARED FOR THE
HUMAN ENGINEERING LABORATORY

BY

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STRESS ANALYSIS OF THE FORCES EXERTED ON A STANDARD 8'x8'x20' ANSI/ISO CONTAINER WHEN THE CONTAINER IS TRANSFERRED FROM THE GROUND TO THE BED OF A PLS TRUCK VIA A HOOKLIFT INTERFACE KIT (HIK)

FINAL REPORT

Contract Number DAAA15-86-D-0013

October 1988

US ARMY HUMAN ENGINEERING LABORATORY
HEL
ABERDEEN PROVING GROUND, MARYLAND

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ABERDEEN PROVING GROUND, MARYLAND 21005-5001

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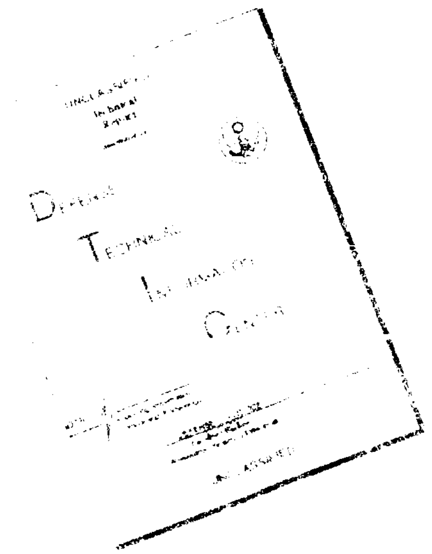

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STRESS ANALYSIS OF THE FORCES EXERTED ON A STANDARD 8'x8'x20' ANSI/ISO CONTAINER WHEN THE CONTAINER IS TRANSFERRED FROM THE GROUND TO THE BED OF A PLS TRUCK VIA A HOOKLIFT INTERFACE KIT (HIK)

CONTRACT NUMBER DAAA15-86-D-0013
Task Order Number: 17

FINAL REPORT

October 1988

By:

A. Lawrence Guess

Prepared For:

Combat Service Support Division
U.S. Army Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

SYSTEMS INTERNATIONAL

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SYSTEMS INTERNATIONAL

11 October 1988

SUBJECT: Transmittal of Final Report, Subject: "Stress Analysis of the Forces Exerted on A Standard 8' x 8' x 20' ANSI/ISO Container when the Container is Transferred from the Ground to the Bed of a PLS Truck VIA a Hooklift Interface Kit (HIK)"

TO: Director
U.S. Army Laboratory Command
ATTN: SLCHE-CS (Mr. John Salser)
Aberdeen Proving Ground, Maryland 21005-5001

Dear Mr. Salser:

Reference is made to Contract Number DAAA15-86-D-0013, Task Order #17.

Subtask #3 of referenced task order calls for the preparation of a stress analysis, subject as above. The Government comments provided on 14 September 1988 based on your review of the 7 September draft, have been incorporated in the final report (triplicate) which is herewith enclosed. Please call Mr. Joe Shearin (301) 272-0800 if there are any questions.

Sincerely,

Bernard C. Witherspoon

Bernard C. Witherspoon
Director
Aberdeen Group

1 Encl (Triplicate)
a/s

A-1

ASI Systems International • Aberdeen Group
211 W Bel Air Avenue, Aberdeen, MD 21001 (301) 272 0800

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EXECUTIVE SUMMARY

The Human Engineering Laboratory (HEL), in concert with the Project Manager, Ammunition Logistics (PM AMMOLOG), is in the process of evaluating the Palletized Loading System (PLS) in the role of an ammunition carrier. As part of this evaluation, a developmental Hooklift Interface Kit (HIK) will be used to upload a standard 8'x8'x20' ISO (International Organization for Standardization) container loaded with ammunition onto a PLS vehicle without the use of the current PLS flatrack. This report presents an engineering stress analysis of the forces exerted on the container as the container is transferred from the ground to the bed of the PLS vehicle.

The container performance specifications established by the ISO and those established by the American National Standards Institute (ANSI) are essentially identical. Consequently, an ISO container is sometimes referred to as an ANSI/ISO container. The primary ISO specification documents are Nos. 668, 1161 and 1496/1. The primary ANSI specification, ANSI MH5.1.1M - 1979, is published by The American Society of Mechanical Engineers (ASME). Military Cargo Containers (MILVANs) are similar to ANSI/ISO containers and adhere to the ANSI/ISO performance specifications as minimum requirements. The primary specification document for MILVANs is MIL-C-52661B(ME), 27 September 1983.

Container detail design is left to the manufacturer. Hence, because there are many different manufacturers, there are many design detail differences in the containers produced by different manufacturers. A key difference, from the standpoint of using a HIK, is the flange width of the lower longitudinal beam. An inspection of various container designs reveals that the flange width varies from from 1/2 inch to 2 inches. With the HIK concept, the lower longitudinal beam flange serves as bearing surface for a substantial concentrated load as the container is pulled onto the PLS vehicle. This stress point occurs at roughly mid-span. Stress analysis indicates that even the 1/2 inch flange will handle the full range of cargo loads, if care is taken to distribute the concentrated load over an adequate area of the flange. However, distribution of the load should prove to be more difficult to design for as the width of the flange decreases. The distribution of the concentrated load is a design requirement placed on the HIK sliding mechanism. Hence, the effectiveness of this mechanism in distributing the reactive load from the PLS vehicle should be a special focus in the HIK evaluation tests. It is recommended that a "narrow flange" container be included in the test program.

Manufacturers consider their container detail design information as proprietary. Therefore, the structural design data used in this analysis was obtained from on-site inspections of an assortment of ISO containers and from a top-level structural drawing provided by the Fruehauf Corporation. (It should be noted that the Fruehauf design is one that has a narrow flange on the lower longitudinal beam.) The Fruehauf design was used as the baseline for the stress analysis, and all critical loading conditions were determined to exhibit adequate Safety Factors. For example, based on the assumption that the container functions structurally as a box beam, the Safety Factor at the container's maximum allowable gross weight of 44,800 pounds is determined to be 3.1.

Another approach used to evaulate the adequacy of the ISO container structural design for the HIK type operation was to examine acceptance test requirements.

Acceptance test requirements for ISO containers are presented in ISO 1496/1, and are summarized in Appendix A of this report. Operationally, the HIK concept subjects the container to a transverse torque as the container is pulled onto the PLS vehicle. This type of load is similar to Test No. 10 in ISO 1496/1. The torque associated with this test is 1.69 times the HIK torque for the 44,800 pound gross weight condition. For a 30,000 pound gross weight condition, the torque margin increases to a factor of 2.58. Again, these Factors of Safety are considered adequate.

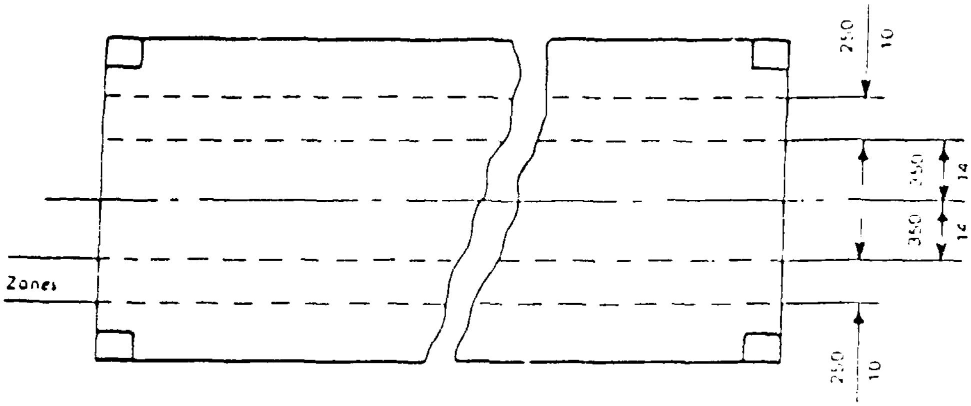
An area of concern is the blocking and bracing of the ammunition load in the container. Steps must be taken to ensure that the load cannot slide and end up being supported by the door-end of the container as one end is lifted onto the PLS vehicle. The container is tested to resist a distributed load on the door-end equal to .4 of its design payload, and for the Fruehauf design, this door-end load is 16,338 pounds. An ammo load of 32,700 pounds, tilted at 30 degrees and free to slide, will yield this magnitude of load.

MILVAN cargo containers are, in general, more rugged than ANSI/ISO containers. This is evident in their respective tare weights. For example, the Fruehauf container tare weight is 3955 pounds, whereas the tare weight for a comparable Type I MILVAN is spec'd at approximately 4700 pounds. Also, the door-end of this type of MILVAN is acceptance tested to a distributed load of 33,280 pounds, compared to a 16,338 pound load for the Fruehauf container. Type II MILVANs, with mechanical restraint systems, appear to be of more rugged design than Type I. Hence, structural stresses on MILVANs should be less severe than those on ANSI/ISO containers during a HIK loading operation.

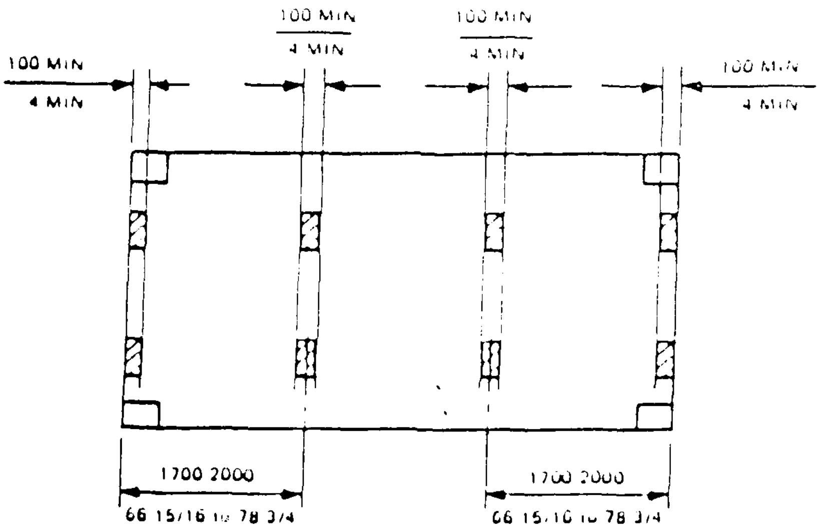
After the container has been loaded onto the PLS vehicle by the HIK, the container must be secured for road travel. It is recommended that the container be rigidly supported on the PLS vehicle by the container's four lower corner fittings. In the description of the HIK design concept, it is not clear how this will be accomplished. Therefore, this should be a point of special focus during the HIK evaluation tests.

1.0 INTRODUCTION

All standard 8'x8'x20' ANSI/ISO containers are designed to be supported by their bottom corner fittings only. In fact, the longitudinal and transverse support beams in the container base structure are spec'd to be a 1/2 inch distance above the bottom face of the corner fittings. However, the containers are also capable of being supported by designated load transfer areas in the base structure. Such areas are located within two 10 inch wide zones defined by the broken lines in Figure 1. There are various methods for lifting the containers by their top corner fittings as well as by the bottom corner fittings. Examples of these methods are noted in Figure 2. (Ref: ANSI MH5.1.1M - 1979)



Load transfer zones



Load transfer areas for 20 ft containers

Millimeter / Inch

Figure 1. Load Transfer Areas

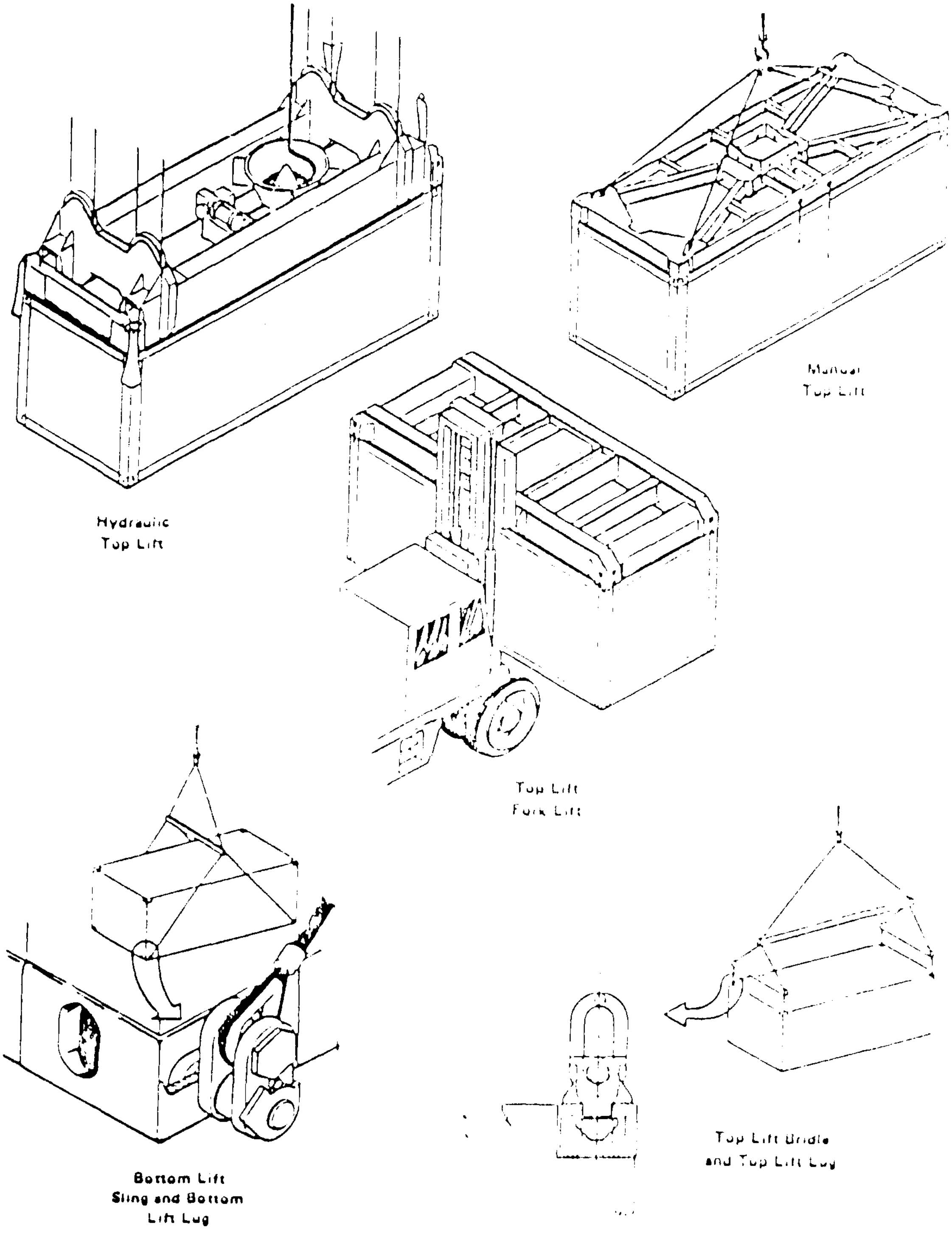


Figure 2. Examples of Methods of Lifting Containers by Corner Fittings

The Hooklift Interface Kit (HIK) concept requires a load transfer area in the container base structure that is outside of the zone specified above. Specifically, load transfer is accomplished using the two outside longitudinal beams (rails) in the base structure. Since the container is not designed for this loading condition, there is concern that an over-stressed situation on the container may exist during a HIK loading operation.

The analysis presented in this report is directed at identifying the major stress points as a container, carrying an ammunition load, is lifted from the ground and placed on a Palletized Loading System (PLS) vehicle without use of the PLS flatrack, as illustrated in Figure 3. The computed forces are compared with the construction specifications of a new container to determine the likelyhood of damage when such a container is picked-up by a PLS vehicle using the HIK concept.

2.0 ANSI/ISO CONTAINER DESIGN CHARACTERISTICS

The design characteristics of ANSI/ISO containers are controlled by performance specifications published by the ASME and the ISO, namely:

a) Requirements for Closed Van Cargo Containers, (ANSI MH5.1.1M - 1979).

b) Series 1 freight containers - Classification, external dimensions and ratings (ISO 668).

c) Series 1 freight containers - Corner fittings - Specification (ISO 1161).

d) Series 1 freight containers - Specification and testing - Part 1: General cargo containers for general purposes (ISO 1496/1).

The design characteristics of MILVAN containers is controlled by the following Military Specification:

a) Containers, Cargo, (MIL-C-52661B(ME), 27 September 1983).

A close tolerance is held on the location of the Corner Fittings, as noted in Figure 4, and tolerances are also specified for the external dimensions, as noted in Table 1. The specific type of container considered in this report is designated "1C." It has the following external dimensions:

Length = 19 ft, 10 1/2 in
Width = 8 ft
Height = 8 ft
Rating = 44,000 lb

The detail design of a container is left up to the manufacturer, and, as a result, there are many design detail differences. However, there should be negligible variation in strength characteristics because of the strengent ISO testing specification (ISO 1496/1). Also, discussions with container users reveal that container fabrication is of good quality for both in-country and over-seas production sources.

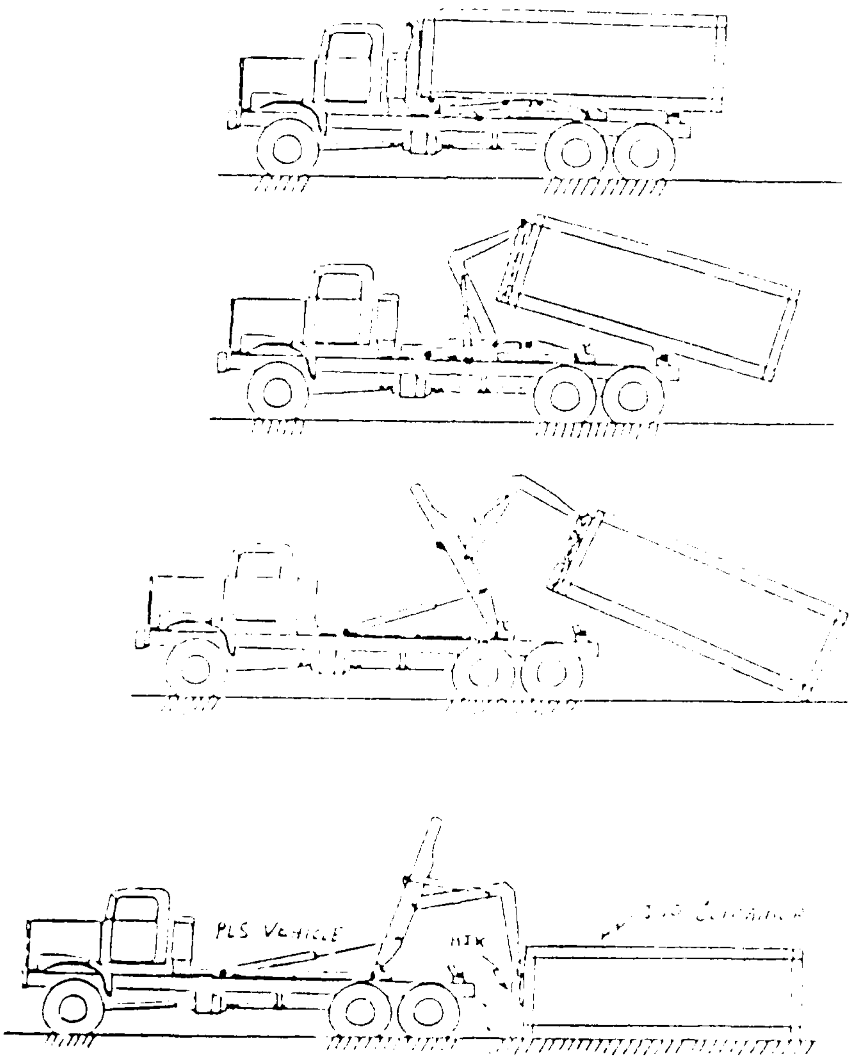
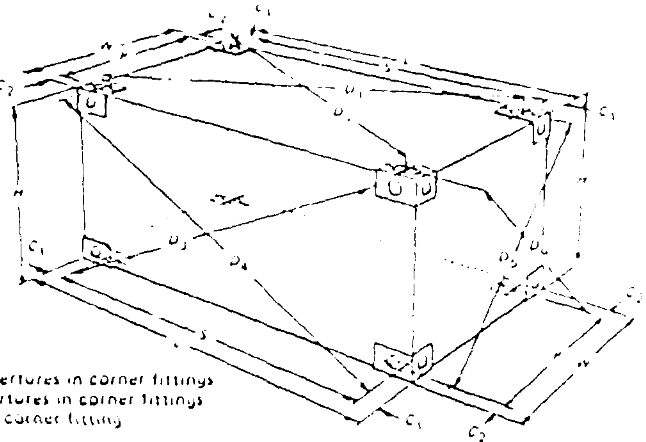


Figure 3. PLS/HIK Concept



S = Length between centers of apertures in corner fittings
P = Width between centers of apertures in corner fittings
C_1 = Distance from outside face of corner fitting to center of aperture
$101.5^{+0}_{-1.5}$ mm ($4^{+0}_{-1/16}$ in)
C_2 = Distance from outside face of corner fitting to center of aperture
$89^{+0}_{-1.5}$ mm ($3\frac{1}{2}{}^{+0}_{-1/16}$ in)
L = External length of container
W = External width of container
D = Distance between centers of apertures of diagonally opposite corner fittings resulting in six measurements, D_1, D_2, D_3, D_4, D_5 and D_6
K_1 = Difference between D_1 and D_2 or between D_3 and D_4, i.e., $K_1 = D_1 - D_2$ or $K_1 = D_2 - D_1$ or $K_1 = D_3 - D_4$ or $K_1 = D_4 - D_3$
K_2 = Difference between D_5 and D_6, i.e., $K_2 = D_5 - D_6$ or $D_6 - D_5$
H = Overall height

Nominal Length feet	Length Overall (L) mm	ft	in	S mm	ft	in.	P mm	ft	in.	K_1 Max mm	in.	K_2 Max mm	in.
40	$12\,192^{+0}_{-10}$	40	$0^{+0}_{-3/8}$	11 985	39	3 7/8	2 259	7	4 31/32	19	3/4	10	3/8
35†	$10\,668^{+0}_{-10}$	35	$0^{+0}_{-3/8}$	10 462	34	3 7/8	2 259	7	4 31/32	17	11/16	10	3/8
30	$9\,125^{+0}_{-10}$	29	$11\frac{1}{4}{}^{+0}_{-3/8}$	8 918	29	3 1/8	2 259	7	4 31/32	16	5/8	10	3/8
24†	$7\,320^{+0}_{-10}$	24	$0\frac{3}{16}{}^{+0}_{-3/8}$	7 113	23	4 1/16	2 259	7	4 31/32	14	9/16	10	3/8
20	$6\,058^{+0}_{-6}$	19	$10\frac{1}{2}{}^{+0}_{-1/4}$	5 853	19	2 7/16	2 259	7	4 31/32	13	1/2	10	3/8

Width Overall (W) 2438^{+0}_{-5} mm (8 ft $0^{+0}_{-3/16}$ in)

Height Overall (H)† 2438^{+0}_{-5} mm (8 ft $0^{+0}_{-3/16}$ in),
2591^{+0}_{-5} mm (8 ft $6^{+0}_{-3/16}$ in),
2743^{+0}_{-5} mm (9 ft $0^{+0}_{-3/16}$ in) or
2896^{+0}_{-5} mm *(9 ft $6^{+0}_{-3/16}$ in)

†Containers built in accordance with MH5 1-1971 may have heights of 2603^{+0}_{-5} mm (8 ft $6\frac{1}{2}{}^{+0}_{-1/4}$ in.)

*The height of 2896 mm (9 ft 6 in.) shall apply only to containers which are provided with tunnel sections at the front end of their understructure for use with gooseneck type chassis.

NOTE Dimensions S and P are reference dimensions only. The tolerances to be applied to S and P are governed by the tolerances shown for the overall length (L) and overall width (W).

Figure 4. Assembled Corner Fitting (Diagonal Tolerances)

TABLE 1 – External dimensions, permissible tolerances and ratings of series 1 freight containers

Freight container designation	Length (*L*)					Width (*W*)				Height (*H*)					Rating (maximum gross mass)	
	mm	Tolerances mm	ft	in	Tolerances in	mm	Tolerances mm	ft	Tolerances in	mm	Tolerances mm	ft	in	Tolerances in	kg	lb
1AA	12 192	0 − 10	40		0 − 3/8	2 438	0 − 5	8	0 − 3/16	2 591*	0 − 5	8	6*	0 − 3/16	30 480	67 200
1A	12 192	0 − 10	40		0 − 3/8	2 438	0 − 5	8	0 − 3/16	2 438	0 − 5	8		0 − 3/16	30 480	67 200
1AX	12 192	0 − 10	40		0 − 3/8	2 438	0 − 5	8	0 − 3/16	< 2 438		< 8			30 480	67 200
1BB	9 125	0 − 10	29	11 1/4	0 − 3/8	2 438	0 − 5	8	0 − 3/16	2 591*	0 − 5	8	6*	0 − 3/16	25 400	56 000
1B	9 125	0 − 10	29	11 1/4	0 − 3/8	2 438	0 − 5	8	0 − 3/16	2 438	0 − 5	8		0 − 3/16	25 400	56 000
1BX	9 125	0 − 10	29	11 1/4	0 − 3/8	2 438	0 − 5	8	0 − 3/16	< 2 438		< 8			25 400	56 000
1CC	6 058	0 − 6	19	10 1/2	0 − 1/4	2 438	0 − 5	8	0 − 3/16	2 591*	0 − 5	8	6*	0 − 3/16	20 320	44 800
1C	6 058	0 − 6	19	10 1/2	0 − 1/4	2 438	0 − 5	8	0 − 3/16	2 438	0 − 5	8		0 − 3/16	20 320	44 800
1CX	6 058	0 − 6	19	10 1/2	0 − 1/4	2 438	0 − 5	8	0 − 3/16	< 2 438		< 8			20 320	44 800
1D	2 991	0 − 5	9	9 3/4	0 − 3/16	2 438	0 − 5	8	0 − 3/16	2 438	0 − 5	8		0 − 3/16	10 160	22 400
1DX	2 991	0 − 5	9	9 3/4	0 − 3/16	2 438	0 − 5	8	0 − 3/16	< 2 438		< 8			10 160	22 400

* In certain countries there are legal limitations to the overall height of vehicle and load

Several on-site inspections were made of an assortment of 8'x8'x20' ISO containers. Also, the Fruehauf Corporation was kind enough to provide a top-level structural drawing of their container design. The most significant variation observed in the various designs was in the shape of the bottom rail cross section. This is illustrated in Figure 5. The 2"x6" channel section should present fewer problems in distributing the load as the HIK pulls the container onto the PLS vehicle. However, an appropriate design of the HIK "sliding mechanism" should be able to accommodate the Fruehauf narrow flange design. The HIK test, of course, should include an examination of this area.

ANSI/ISO containers are rugged structures with substantial load carrying capability, see Appendix A. Also, it is assumed that an ammunition load will be rigidly blocked and braced within the container. Therefore, for this analysis, the assumption is made that the container performs structurally as a rigid box-beam structure with logitudinal forces and bending moments being reacted by the top and bottom longitudinal beams.

The Fruehauf design is used as a baseline for this analysis, because of the greater amount of detailed information that has been made available. This design is presented in Figure 6, and the associated General Specifications are included in Appendix B. Additional detail on this design is considered Company proprietary information. Therefore, the following data are "best estimates" based on the analyst' judgement:

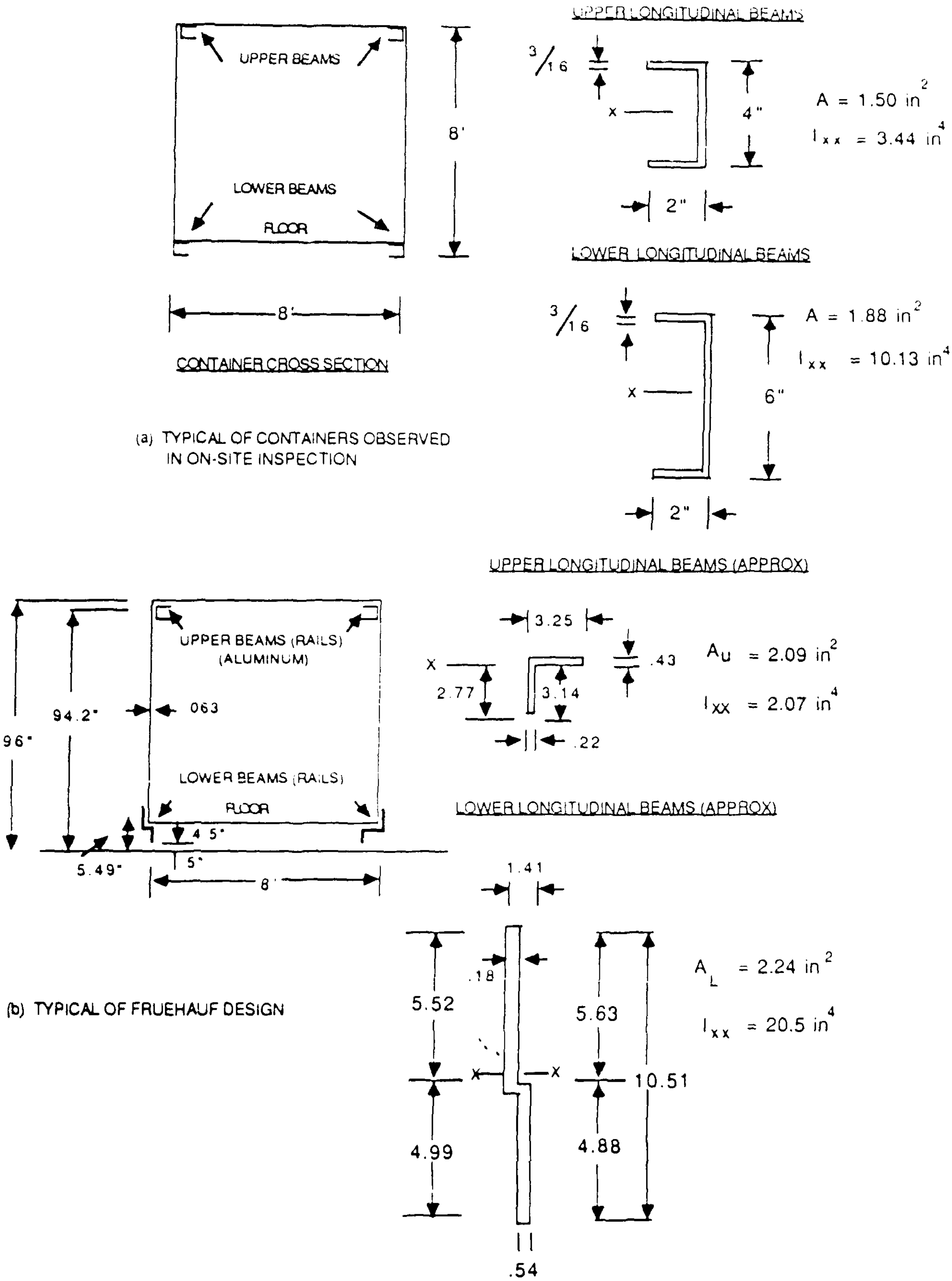
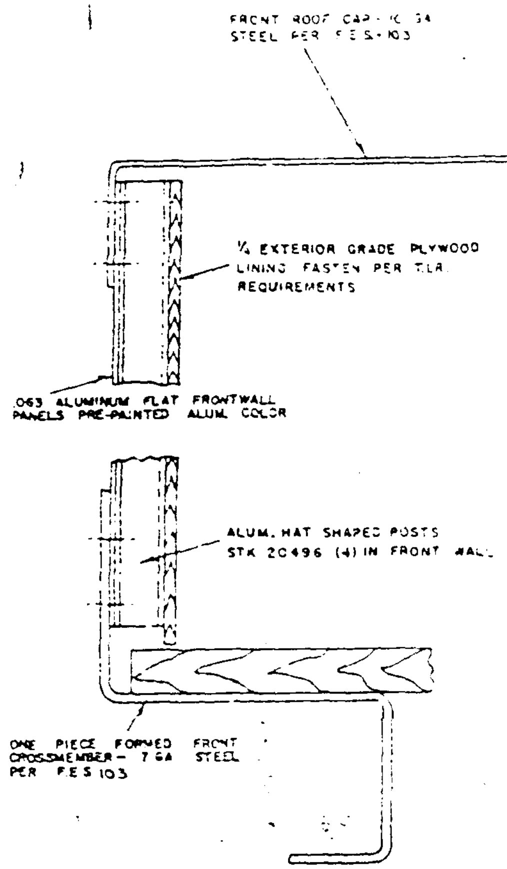
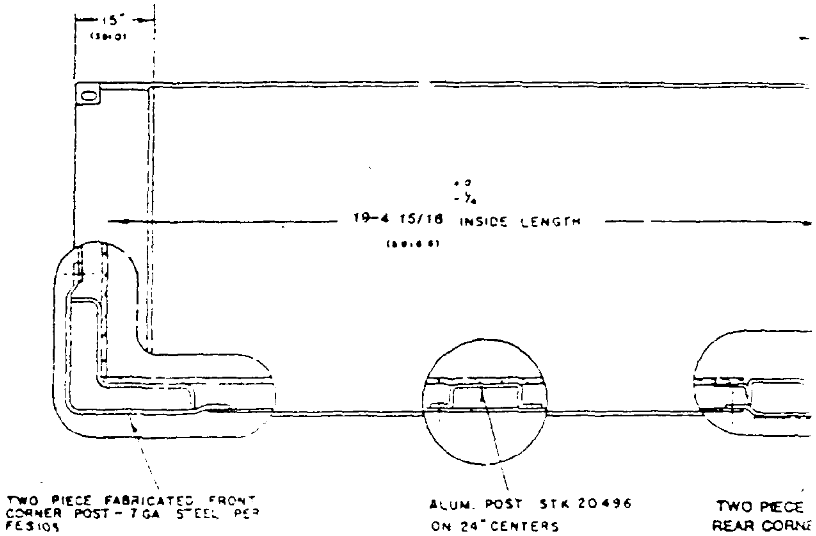
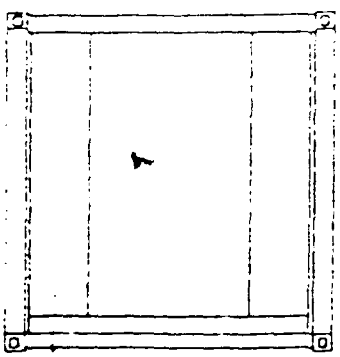


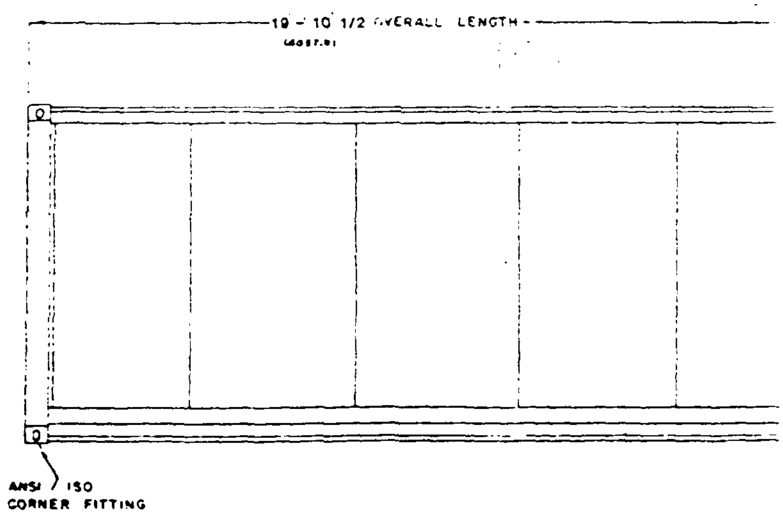
Figure 5. Variations in Top and Bottom Beam (Rail) Designs



FRONT WALL SECTION







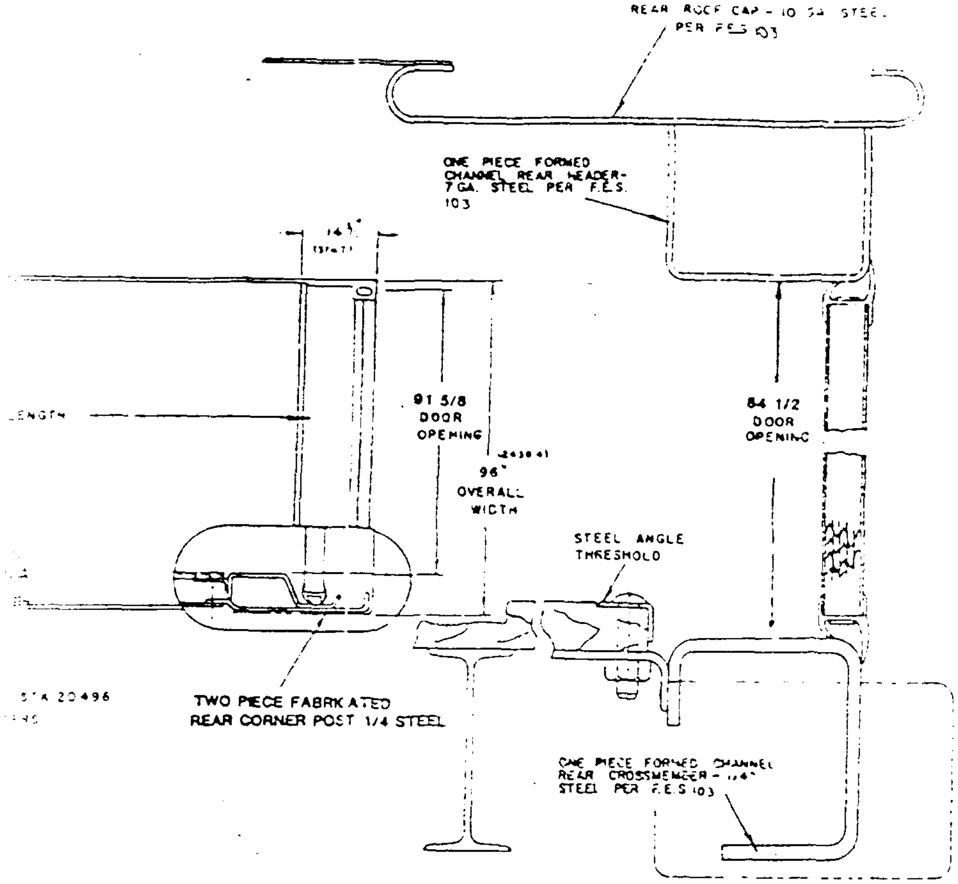
GENERAL SPECIFICATIONS

CORNER POSTS FOR SIX HIGH STACKING
ALL HARDWARE: HOT DIPPED GALVANIZED
HARDWARE FASTENERS: CADMIUM PLATE AND CHROMATE DIPPED
ALUM. FASTENERS: SOLID ALUM. NO FINISH
END FRAMES & LOWER SIDE RAILS TO BE PAINTED WITH HEMPEL'S TWO COAT FINISH

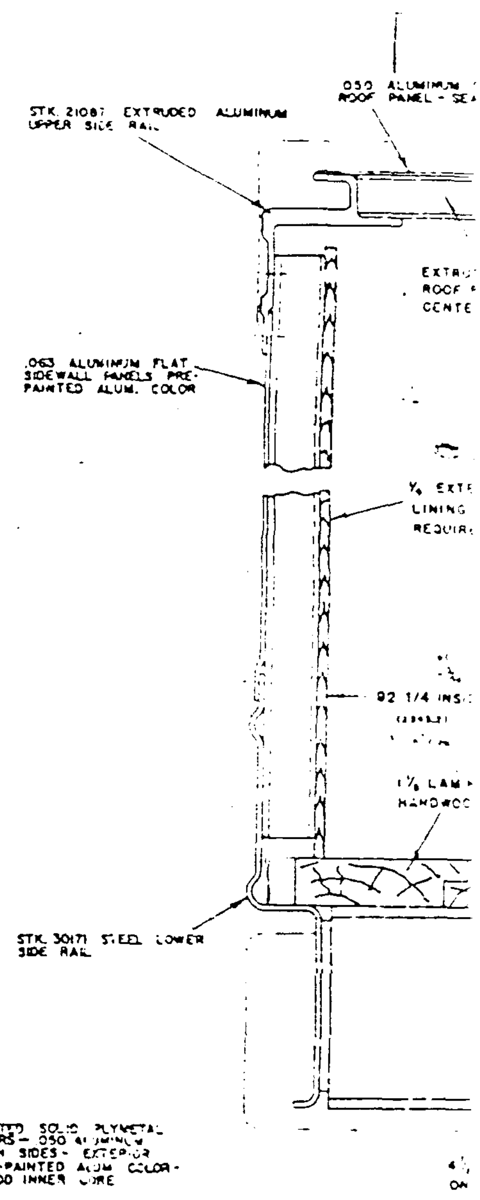
IN ALL CASES WHERE DISSIMILAR METALS CONTACT THEY ARE PROTECTED FROM GALVANIC CORROSION BY USE OF AN ELECTROLYTICALLY INSULATED TAPE

CONTAINER MEETS THE FOLLOWING REQUIREMENTS:

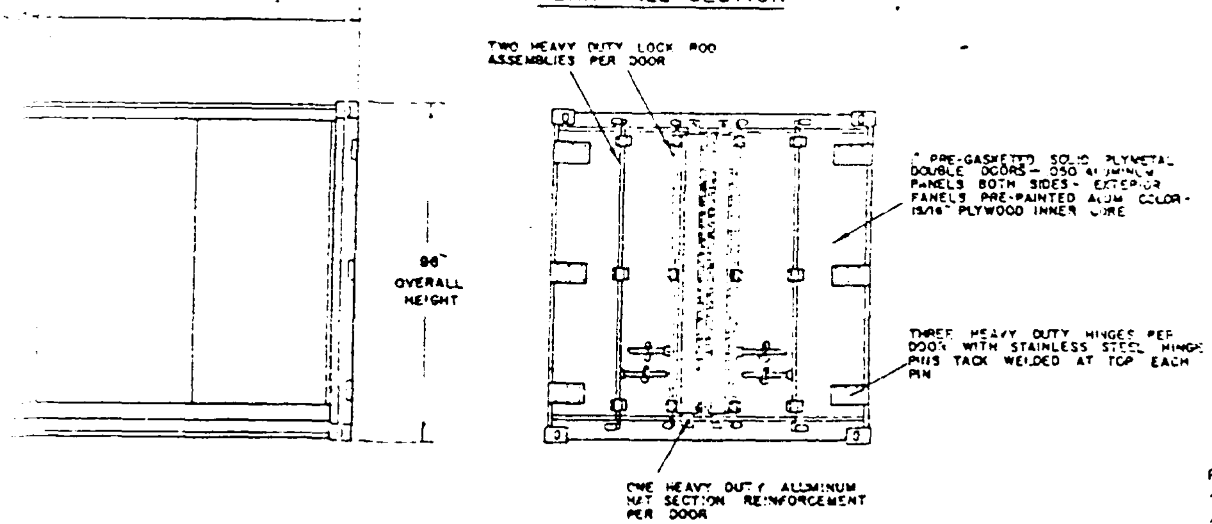
ALL APPLICABLE ANSI AND ISO AS OF DATE OF MANUFACTURE
ABS - 1968 USED FOR CERTIFICATION OF CARGO CONTAINERS
CSC - INCLUDING CERTIFICATION PLATE AND REQUIRED INFORMATION
TIR - FEDERAL REGISTER, VOL. 34 NO 169, 9-4-69



REAR WALL SECTION



BODY SECTION



RATED GROSS WEIGHT - 44,8
TARE WEIGHT - 3855 lbs.
CUBIC CAPACITY - 1991 CU. FT.

FIGUR

8-ND989A

CUSTOMER:

DLG 5-13-84

FRUEHAUF CORPORATION

CONTAINER

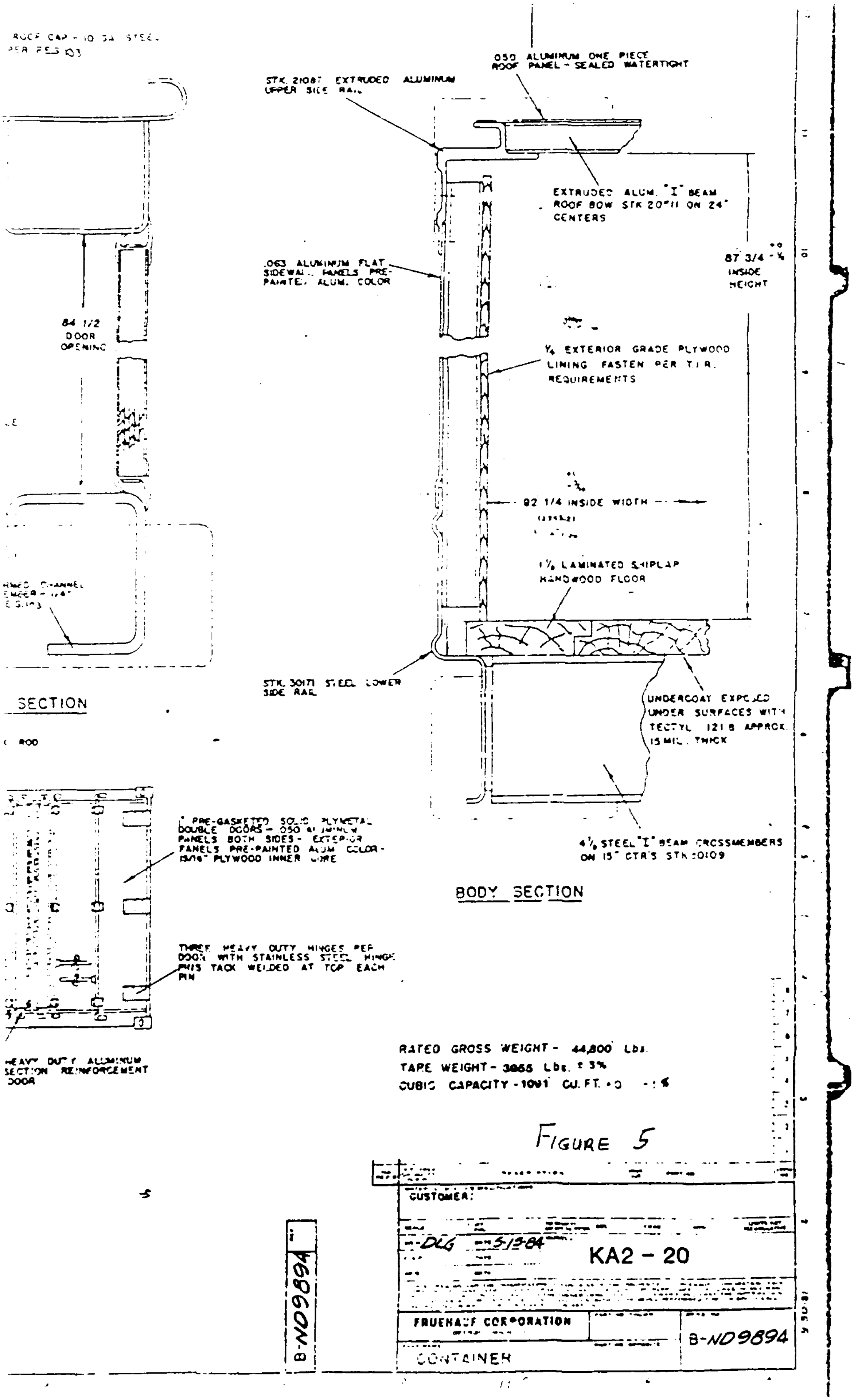

.050 ALUMINUM ONE PIECE ROOF PANEL - SEALED WATERTIGHT
STK. 21087 EXTRUDED ALUMINUM UPPER SIDE RAIL
EXTRUDED ALUM. "I" BEAM ROOF BOW ON 24" CENTERS
.063 ALUMINUM FLAT SIDEWALL PANELS PRE-PAINTED ALUM. COLOR
87 3/4 INSIDE HEIGHT
84 1/2 DOOR OPENING
1/4 EXTERIOR GRADE PLYWOOD LINING FASTEN PER T.I.R. REQUIREMENTS
92 1/4 INSIDE WIDTH
1 1/8 LAMINATED SHIPLAP HARDWOOD FLOOR
STK. 30171 STEEL LOWER SIDE RAIL
UNDERCOAT EXPOSED UNDER SURFACES WITH TECTYL 121 B APPROX. 15 MIL. THICK
4 1/2 STEEL "I" BEAM CROSSMEMBERS ON 15" CTR'S
SECTION
BODY SECTION
PRE-GASKETED SOLID PLYMETAL DOUBLE DOORS - .050 ALUMINUM PANELS BOTH SIDES - EXTERIOR PANELS PRE-PAINTED ALUM. COLOR - 15/16" PLYWOOD INNER CORE
THREE HEAVY DUTY HINGES PER DOOR WITH STAINLESS STEEL HINGE PINS TACK WELDED AT TOP EACH PIN
HEAVY DUTY ALUMINUM SECTION REINFORCEMENT DOOR
RATED GROSS WEIGHT - 44,800 Lbs.
CUSTOMER:
DLG 5-15-84
KA2 - 20
FRUEHAUF CORPORATION
B-ND9894
CONTAINER
B-ND9894A

Figure 5

Weight Breakdown -

Bottom Structure (longitudinal beams, cross members, floor, front and rear lower beams)	1951 lb
Top Structure (longitudinal beams, cross members, roof caps, roof, rear door header)	403 lb
Front and Side Walls (corner posts, stiffiners, sheet and plywood)	1089 lb
Door (siding, hardware)	371 lb
Miscelaneous (corner fittings, etc.)	141 lb
TOTAL	3955 lb

Empty Container Center of Gravity -

X_{CG_C} = 9.26 ft (from door end of container)
Y_{CG_C} = 2.90 ft (from ground)

Cross Section Properties (see Appendix C) -

Y_{NA} = 2.21 ft (from ground)
I_{TOT} = 8405 in^4
Q_{NA} = 99.66 in^3

based on uniform steel construction

3.0 HIK DESIGN CHARACTERISTICS

The HIK configuration is illustrated in Figure 7. The following characteristics have been assumed for the HIK:

HIK Weight -

W_H = 1200 lb

HIK Center of Gravity -
X_{CG_H} = 20.5 ft (from door end of container)
Y_{CG_H} = 4.0 ft (from ground)

The baseline container design equipped with a HIK is illustrated in Figure 8.

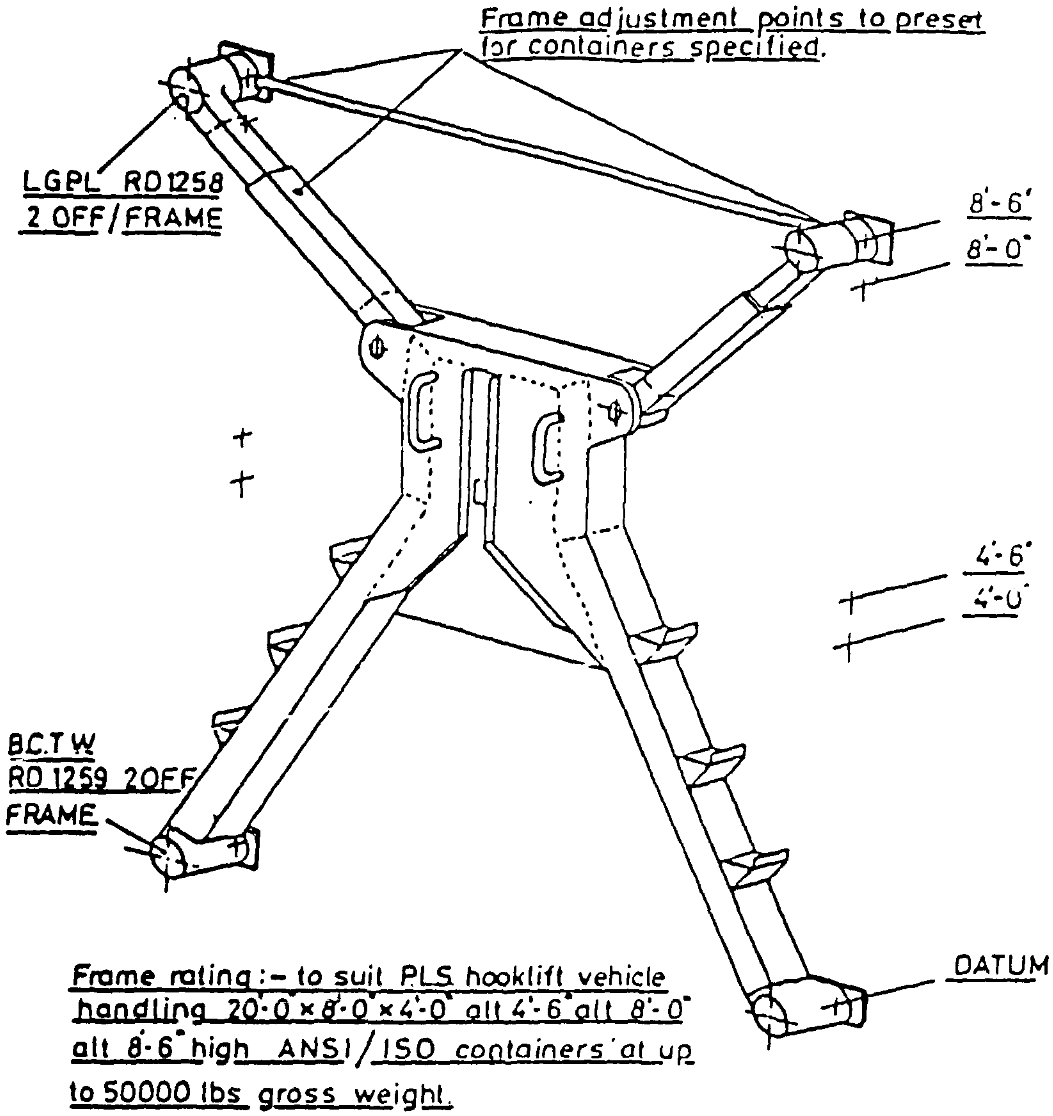


Figure 7. HIK Configuration Sketch

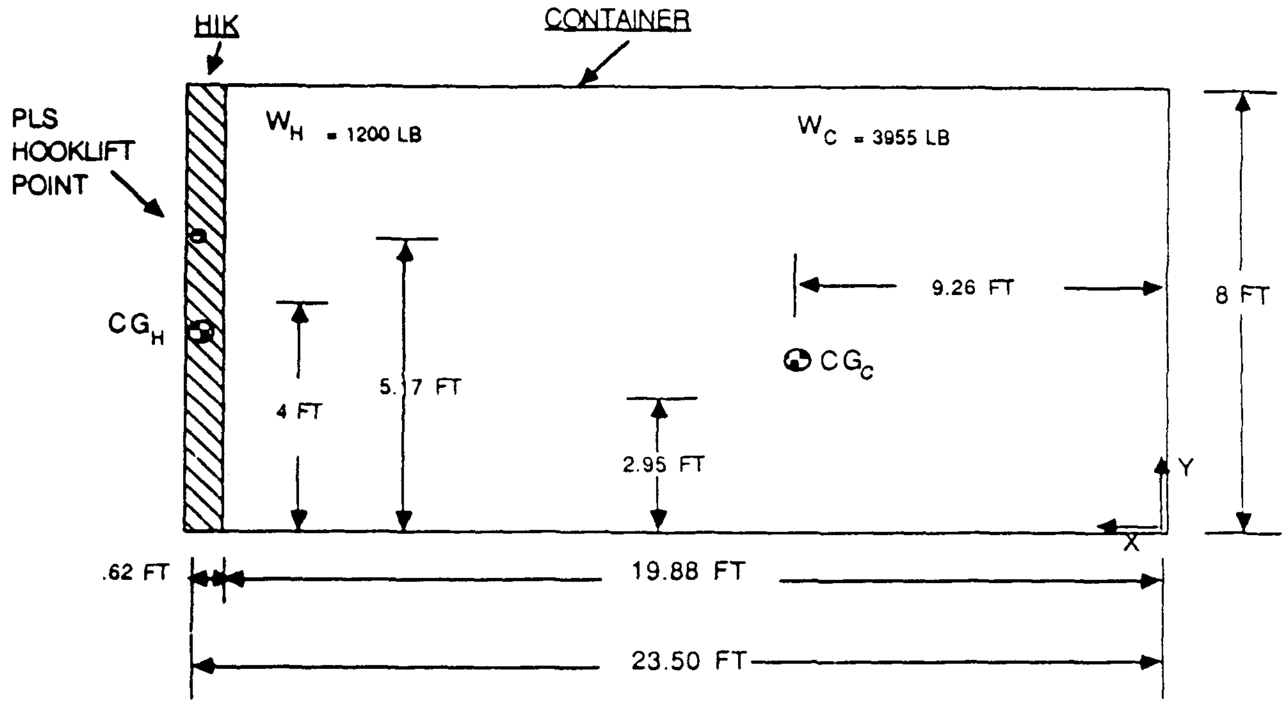


Figure 8. Baseline Container/HIK Configuration

4.0 TOTAL LOAD CHARACTERISTICS

Total weight is carried as a variable in this analysis. Total Weight is defined as follows:

$$W_{TOT} = W_C + W_H + W_P \qquad (1)$$

where:

W_{TOT} = Total Weight of Container/HIK/Payload

W_C = Weight of Empty Container

W_H = Weight of HIK

W_P = Payload Weight

The range of values used for W_{TOT} is 30,000 to 50,000 pounds.

The Payload Weight is assumed to be uniformly distributed, and to be comparable in density to the load on a standard 40"x48"x48" ammo pallet weighing 2188 pounds:

$$\rho = \frac{2188\ (1728)}{40(48)(48)} = 41\ \text{lb/FT}^3 \qquad (2)$$

The center of gravity of the payload is determined as follows:

$$X_{CGP} = \frac{1}{2}\,(19.88) = 9.94\ \text{FT} \qquad (3)$$

$$Y_{CGP} = \frac{1}{2}\,\frac{W_P}{(19.41 \times 7.64)\rho} + \frac{6.5}{12} \qquad (4)$$

$$= \frac{W_P}{12167} + 0.54 \qquad (5)$$

This leads to the following expressions for the total Container/HIK/Payload configuration:

$$W_{TOT} = 5155 + W_P \qquad (6)$$

$$X_{CGTOT} = \frac{9.26(3955) + 20.50(1200) + 9.94(W_P)}{5155 + W_P} \qquad (7)$$

$$= \frac{61223 + 9.94\ W_P}{5155 + W_P} \qquad (8)$$

$$Y_{CGTOT} = \frac{2.90(3955) + 4.00(1200) + \left(\frac{W_P}{12167} + 0.54\right) W_P}{5155 + W_P} \qquad (9)$$

$$= \frac{16270 + \left(\frac{W_P}{12167} + 0.54\right) W_P}{5155 + W_P} \qquad (10)$$

The center of gravity location for the total Container/HIK/Payload configuration, as a function of total weight, is plotted in Figure 9.

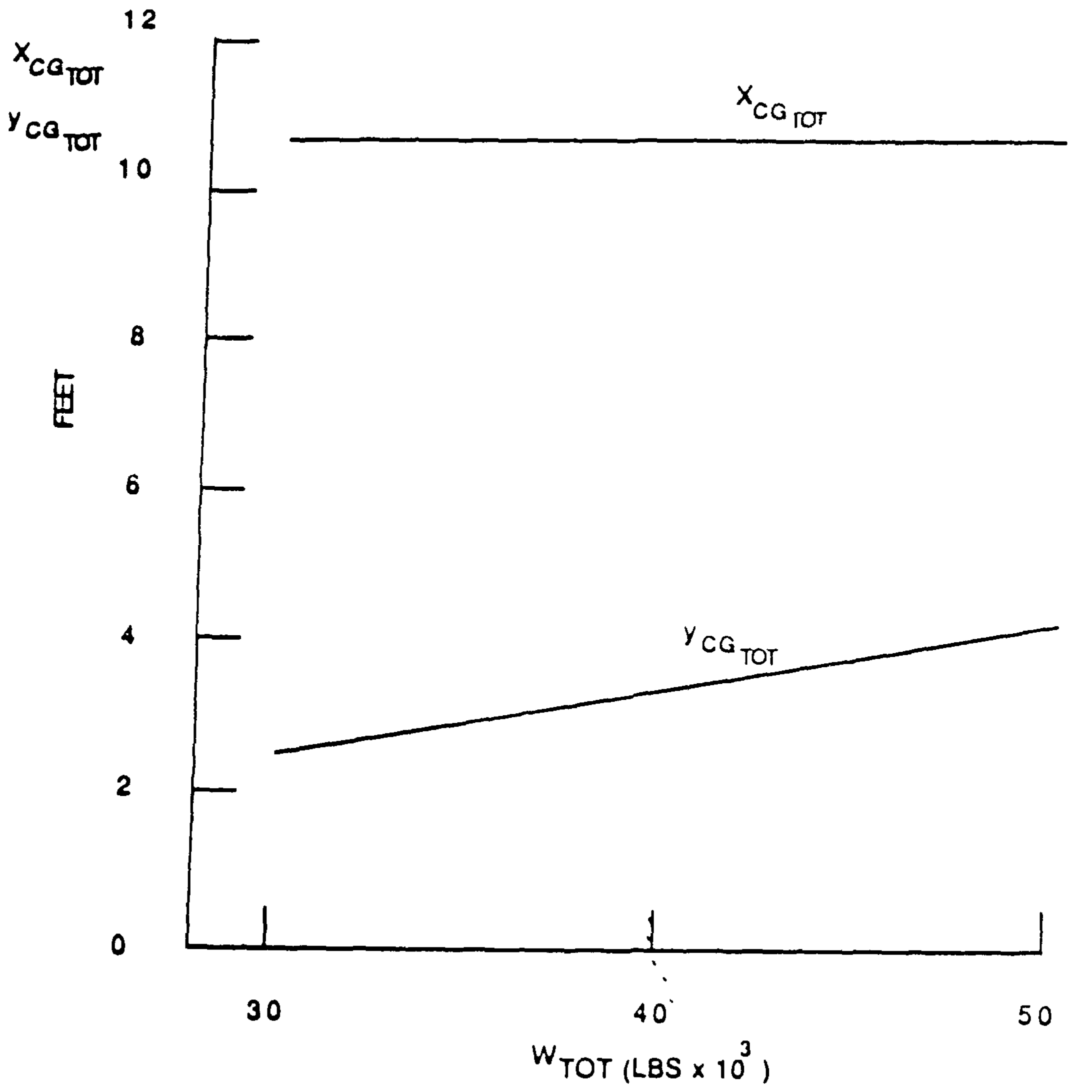


Figure 9. Center of Gravity (Total Configuration)

5.0 LOADS ANALYSIS MODEL

Three basic loading conditions are examined, namely,

Condition 1 - Initial Lift of the container from the Ground by the PLS

Condition 2 - Initial Contact of the container with the rear of the PLS Vehicle

Condition 3 - Initial Movement of the container onto the PLS Vehicle

The model used to relate the container to the PLS vehicle is presented in Figure 10(a). Note that up until the container is well past half-way onto the PLS vehicle, the PLS lifting arm angle, defined as "λ," is a constant value. In other words, the distance between points A and B remains at a constant value "m." The angle parameters used in this model are defined in Figure 10(b).

Following is a listing of the numerical values used for the constants defined in Figures 10(a) and 10(b):

a = 4.50 ft
b = 5.17 ft
e = 4.75 ft
f = 5.92 ft
m = 9.50 ft
L = 20.50 ft

Based on the configuration arrangement depicted in Figures 10a and 10b, the following geometrical relationships, which describe the movement of the container onto the PLS vehicle, can be derived:

$$\eta = \sqrt{b^2 + L^2} \tag{11}$$

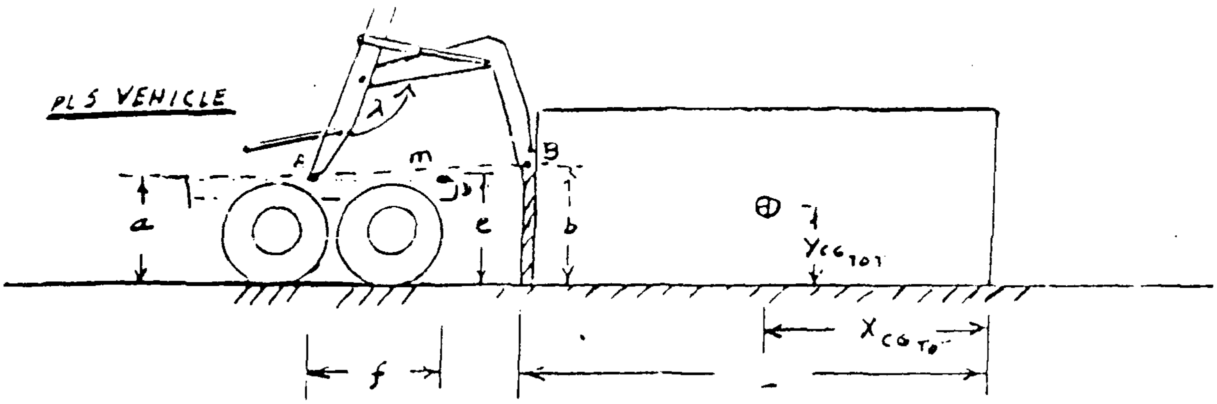
$$\alpha = \tan^{-1} \frac{b}{L} \tag{12}$$

$$\beta = \sin^{-1} \frac{(m \sin \theta + a)}{\eta} \tag{13}$$

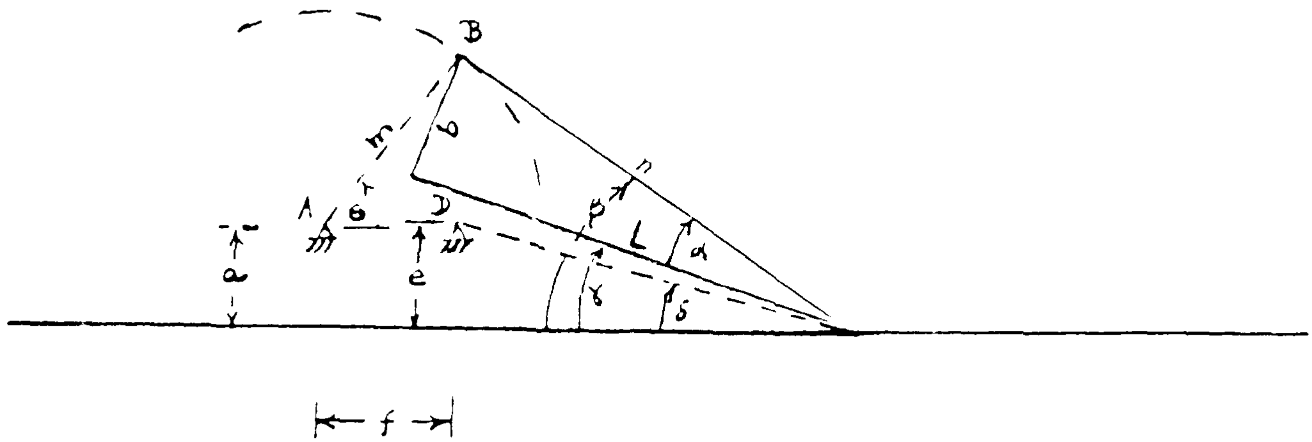
$$\gamma = \beta - \alpha \tag{14}$$

$$\delta = \tan^{-1} \frac{e}{m \cos \theta + \eta \cos \beta - f} \tag{15}$$

Substituting into these equations the values for a,b,e,f,m and L,



(a)



(b)

Figure 10. Dimensional Model

$$\eta = \sqrt{(5.17)^2 + (20.50)^2} = \underline{21.14} \text{ ft} \tag{16}$$

$$\alpha = \tan^{-1} \frac{5.17}{20.50} = \underline{14.15}^{\circ} \tag{17}$$

$$\beta = \sin^{-1} \frac{(9.50 \sin\theta + 4.50)}{21.14} \tag{18}$$

$$\delta = \tan^{-1} \frac{4.75}{9.50 \cos\theta + 21.14 \cos\beta - 5.92} \tag{19}$$

Movement onto the PLS vehicle begins when $\gamma = \delta$. The value of γ at this condition is defined here as γ_C. A graphical solution of Equations 14 and 19 is used to solve for γ_C, (see Figure 11). This procedure yields the following value for γ_C:

$$\gamma_C = 27.2^{\circ} \tag{20}$$

The distance along the container bottom, from the end touching the ground to the point of contact with the PLS vehicle, is defined as L_D. The value of L_D is computed as follows:

$$L_D = \frac{\text{[illegible]}}{\sin \gamma_C} \tag{21}$$

$$= \frac{4.75}{\sin 27.2} = \underline{10.39} \text{ ft} \tag{22}$$

6.0 LOADS AND STRESS ANALYSIS

6.1 Condition 1 - Initial Lift of the container from the ground by the PLS.

This condition is examined primarily for reference purposes, since the loads incurred are essentially the same as those for a normal ISO container loading operation. The load distribution is illustrated in Figure 12. The Friction Force (F) arises from the movement of the container toward the PLS vehicle as the PLS lifting arm lifts its end of the container. Of course, the PLS vehicle will be moved toward the container as the end is lifted, i.e., backing-up the PLS will negate the friction force. However, it is more conservative in the loads analysis to assume that the friction force is present. From the loads distribution in Figure 12, the following equations can be written:

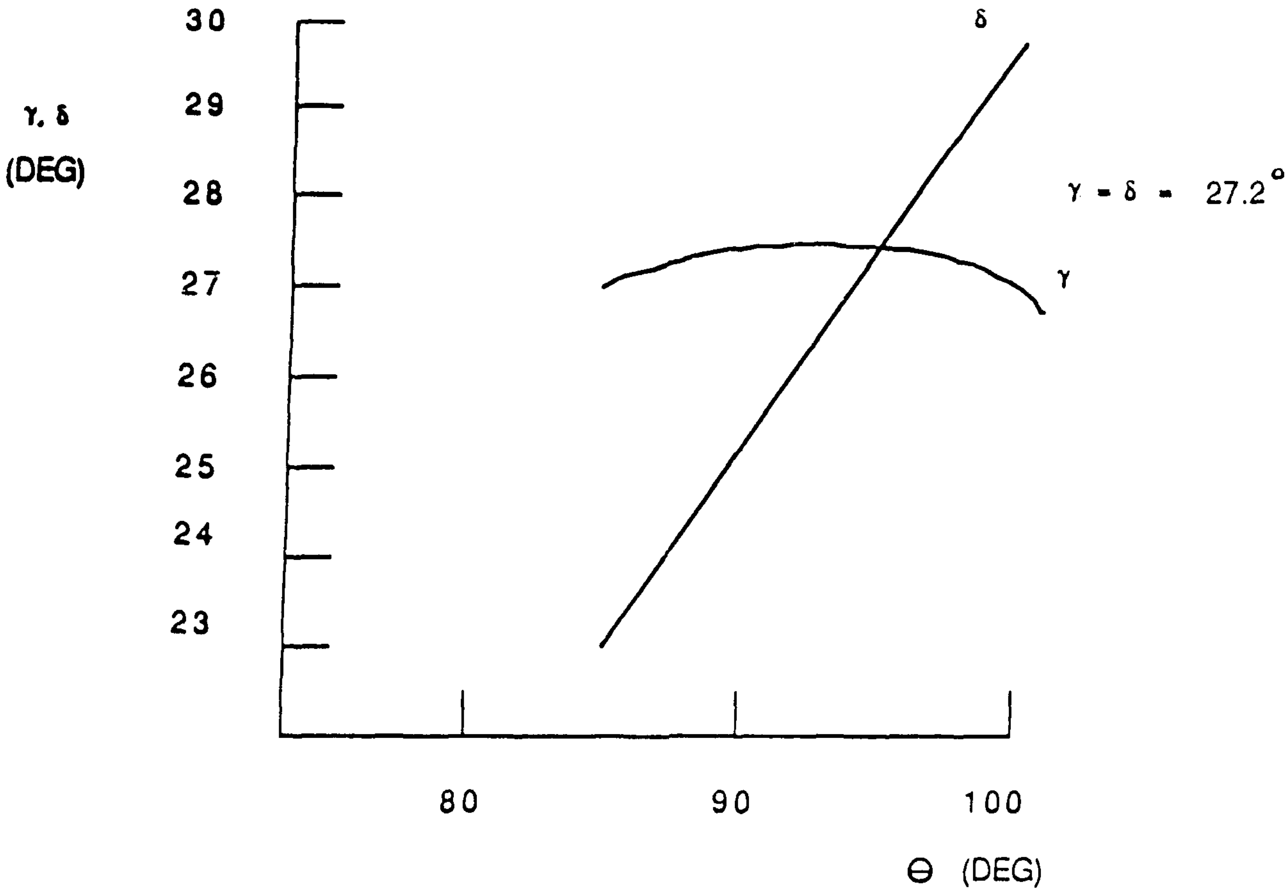


Figure 11. Graphical Solution for $\gamma = \delta$

$$\Sigma F_X = P_X - F = 0 \tag{23}$$

$$\Sigma F_Y = P_Y + R_A - W_{TOT} = 0 \tag{24}$$

$$\Sigma M_A = W_{TOT}(X_{CG_{TOT}}) + P_X(b) - P_Y(L) = 0 \tag{25}$$

$$F = \mu R_A \tag{26}$$

$$P_X = \mu R_A \tag{27}$$

$$R_A = W_{TOT} - P_Y \tag{28}$$

$$W_{TOT}(X_{CG_{TOT}}) = P_Y(L) - P_X(b) \tag{29}$$

From EQ. 27 & 28:

$$R_A = \frac{P_X}{\mu} = W_{TOT} - P_Y \tag{30}$$

OR:

$$W_{TOT} = \frac{P_X}{\mu} + P_Y \tag{31}$$

From EQ. 29 + 31:

$$\frac{P_X}{\mu} + P_Y = P_Y \frac{L}{X_{CGTOT}} - P_X \frac{b}{X_{CGTOT}} \tag{32}$$

$$P_X\left(\frac{1}{\mu} + \frac{b}{X_{CGTOT}}\right) = P_Y\left(\frac{L}{X_{CGTOT}} - 1\right) \tag{33}$$

$$\frac{P_X}{\mu} = P_Y \frac{(L - X_{CG_{TOT}})}{(X_{CG_{TOT}} + \mu b)} \tag{34}$$

From EQ 31 & 34:

$$P_Y = \left[\frac{X_{CG_{TOT}} + \mu b}{L - \mu b}\right] W_{TOT} \tag{35}$$

$$R_A = W_{TOT} - P_Y \tag{36}$$

$$P_X = \mu R_A \tag{37}$$

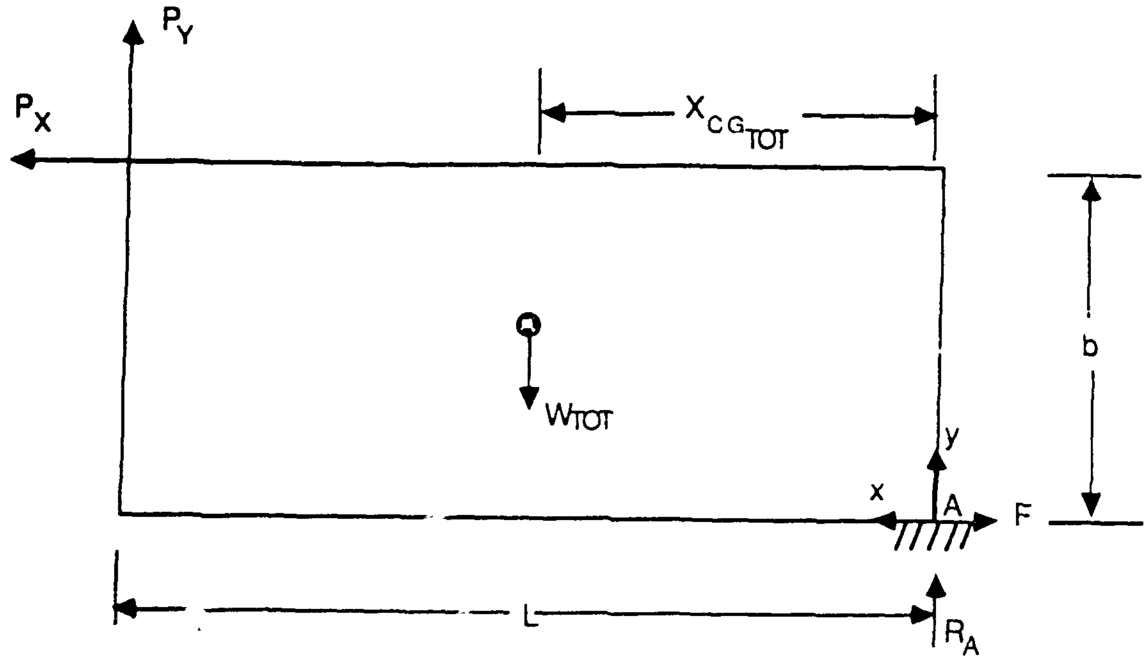


Figure 12. Condition 1, External Loads

Solutions to EQ 35, 36 and 37 are plotted in Figure 13. Note a value of 0.2 is assumed for μ. Also shown in Figure 13 are the shapes of the Shear and Bending Moment Diagrams.

The equation for the Maximum Bending Moment is as follows:

$$M_{MAX} = R_A(X_M) + 0.2R_A(Y_{NA}) - \frac{(X_M)^2}{2(10.88)}(W_{TOT}-W_H) \qquad (38)$$

Where:

$$X_M = \frac{R_A L_C}{R_A + P_Y - W_H} \qquad (39)$$

Equation 38 is plotted in Figure 14.

The Maximum Stress in the longitudinal beams is estimated as follows: (1/3 used to convert back to aluminum upper beam).

$$\sigma_{MAX_u} = [-\frac{M_{MAX}\,C_u}{I_{TOT}} + \frac{P_{xu}}{2(A_u)}]\frac{1}{3} \qquad (40)$$

$$= [-\frac{M_{MAX}}{8405}(95-26.53)(12) + \frac{(26.53-2)}{92}(\frac{P_x}{2(\frac{1}{3})(2.09)})]\frac{1}{3} \qquad (41)$$

$$= -\frac{M_{MAX}}{30.69} + \frac{P_X}{15.69} \qquad (42)$$

$$\sigma_{MAX_L} = \frac{M_{MAX}C_L}{I_{TOT}} + \frac{P_{XL}}{2(A_L)} \qquad (43)$$

$$= \frac{M_{MAX}}{8405}(26.53 - 0.5)(12) + \frac{[92-(26.53-2)]}{92}(\frac{P_X}{2(2.24)}) \qquad (44)$$

$$= \frac{M_{MAX}}{26.91} + \frac{P_X}{6.11} \qquad (45)$$

The Maximum Shear Stress in the sidewalls is estimated as follows:

$$\tau_{MAX} = [\frac{V\,Q}{I_{TOT}\tau}]\frac{1}{3} \qquad (46)$$

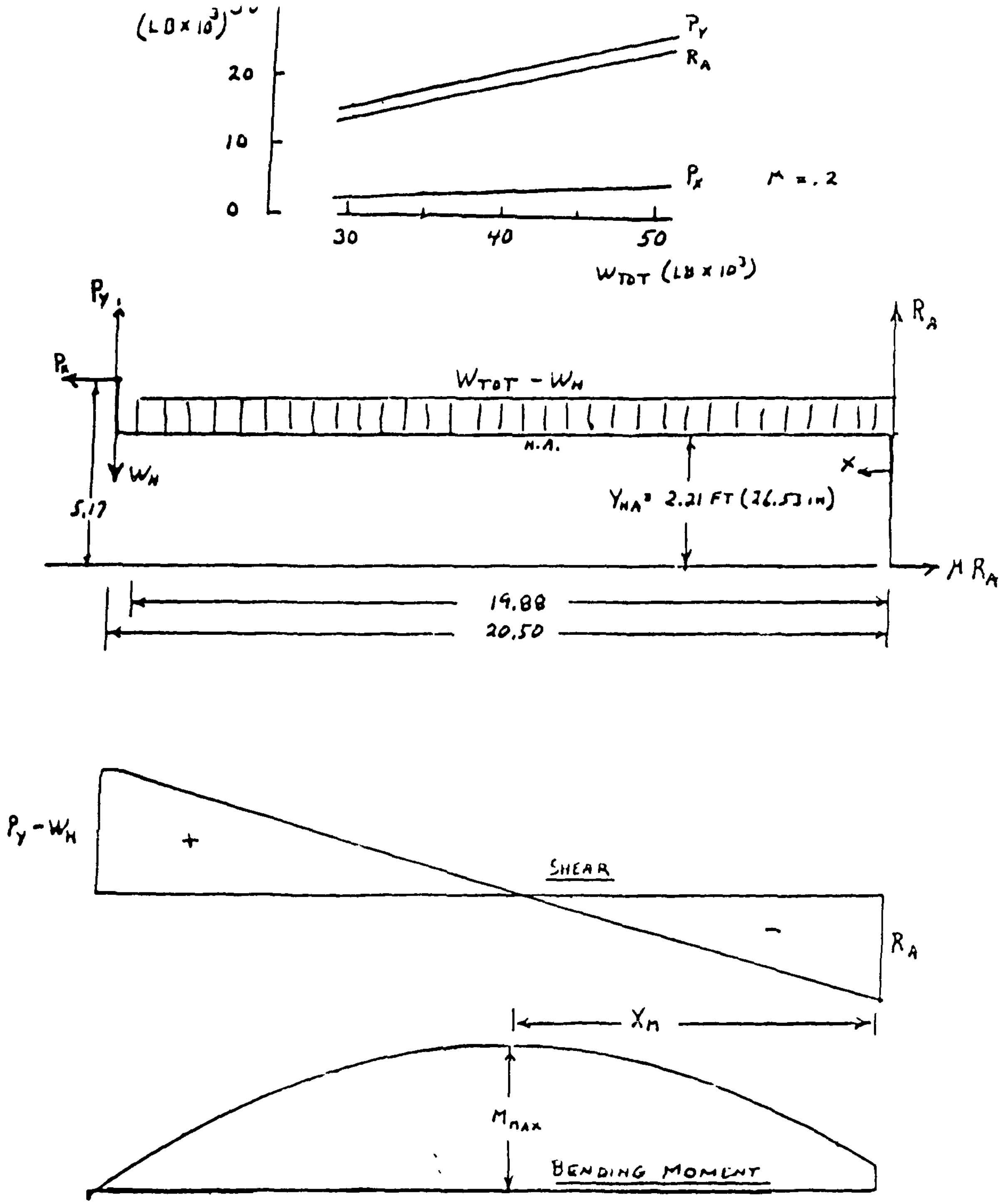


Figure 13. Condition 1, Force and Bending Moment Distribution

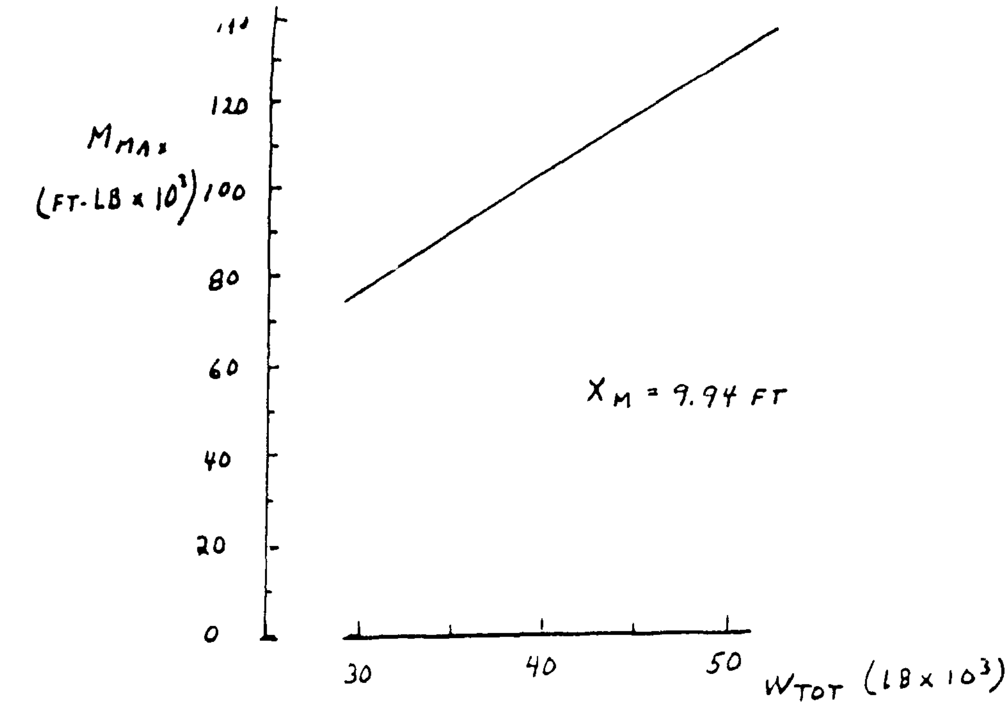


Figure 14. Condition 1, Maximum Bending Moment

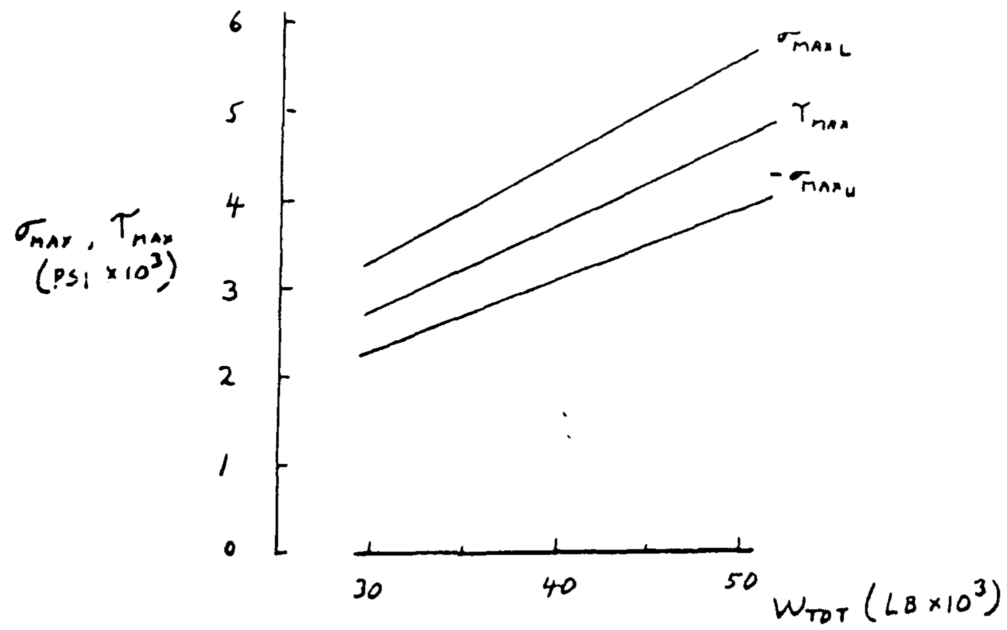


Figure 15. Condition 1, Maximum Stress

$$= \left[\frac{(P_Y - W_H)\ 99.66}{8405(0.021)}\right]\frac{1}{3} \qquad (47)$$

$$= \frac{P_Y - W_H}{5.31} \qquad (48)$$

Equations 42, 45 and 48 are plotted in Figure 15.

The following values are assumed for σ_{yield} and τ_{yield}:

$$\sigma_{Yield} = 30{,}000 \text{ PSI} \qquad (49)$$

$$\tau_{Yield} = 20{,}000 \text{ PSI} \qquad (50)$$

For W_{TOT} = 44,800 LB, the following Safety Factors (FS) are computed:

$$FS_U = \frac{30000}{3472} = 8.64 \text{ (Upper Beam)} \qquad (51)$$

$$FS_L = \frac{30000}{4977} = 6.03 \text{ (Lower Beam)} \qquad (52)$$

$$FS_W = \frac{20000}{4160} = 4.81 \text{ (Side Wall)} \qquad (53)$$

6.2 Condition 2 - Initial Contact of the container with the Rear of the PLS Vehicle.

This condition is examined to determine the container loading conditions just prior to starting the pulling of the container onto the PLS vehicle. At this point, the container is tilted on its end at an angle of 27.2 degrees. The forces being exerted on the container are noted in Figure 16. Based on this load distribution, the following equations can be written:

$$\left.\begin{aligned}
\Sigma F_X &= P_X - F\cos\gamma_C + R_A \sin\gamma_C - W_{TOT}\sin\gamma_C = 0 && (54)\\
\Sigma F_Y &= P_Y + F\sin\gamma_C + R_A\cos\gamma_C - W_{TOT}\cos\gamma_C = 0 && (55)\\
\Sigma M_A &= W_{TOT}(\eta_{CG})\cos\varphi + P_X b - P_Y L = 0 && (56)\\
F &= \mu R_A && (57)
\end{aligned}\right\}$$

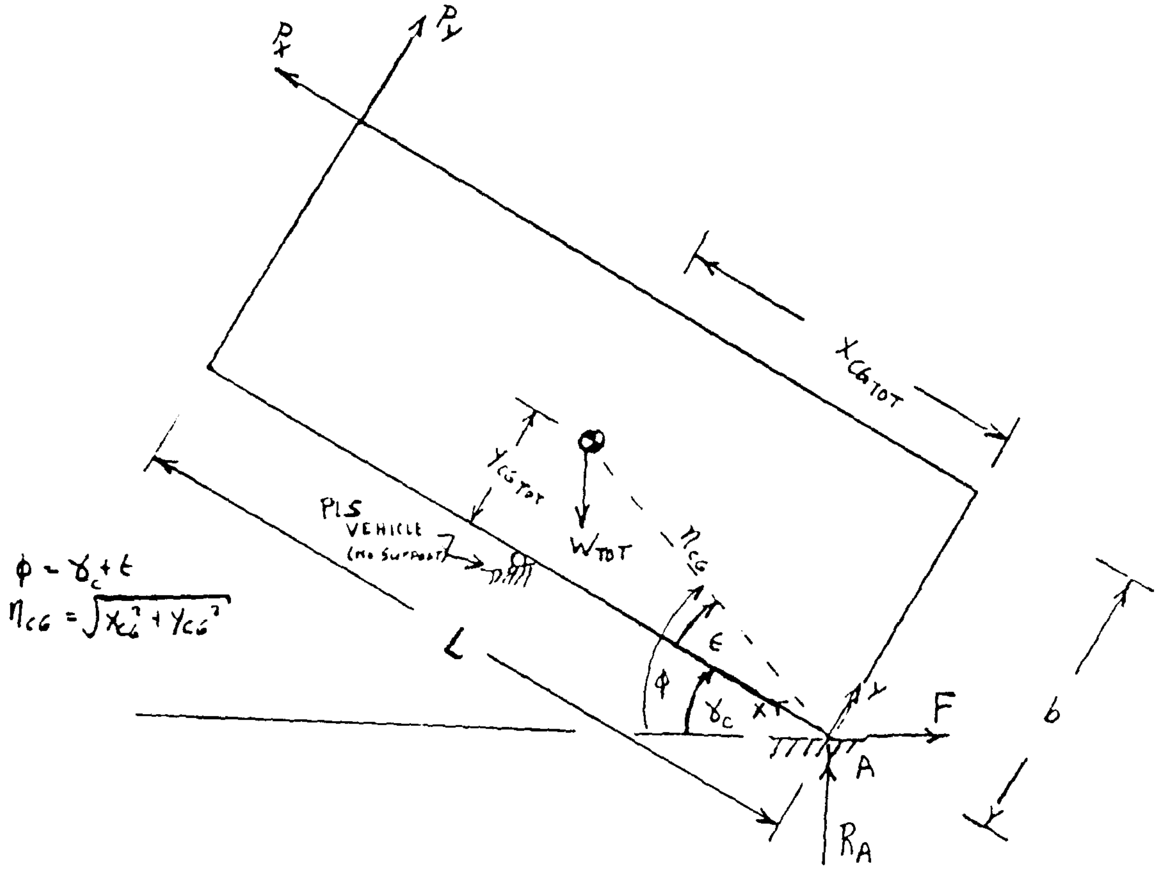


Figure 16. Condition 2, External Loads

From EQ 54,

$$P_X = \mu R_A \cos \gamma_C - R_A \sin \gamma_C + W_{TOT} \sin \gamma_C \qquad (58)$$

$$= R_A(\mu \cos \gamma_C - \sin \gamma_C) + W_{TOT} \sin \gamma_C \qquad (59)$$

From EQ 55,

$$\mu R_A \sin \gamma_C + R_A \cos \gamma_C = W_{TOT} \cos \gamma_C - P_Y \qquad (60)$$

$$R_A = \frac{1}{\mu \sin \gamma_C + \cos \gamma_C} (W_{TOT} \cos \gamma_C - P_Y) \qquad (61)$$

From EQ 56,

$$W_{TOT}(\eta_{CG}) \cos \varphi = P_Y L - P_X b \qquad (62)$$

From EQ 59 and 61,

$$\frac{1}{(\mu \cos \gamma_C - \sin \gamma_C)} (P_X - W_{TOT} \sin \gamma_C)$$
$$= \frac{1}{(\mu \sin \gamma_C + \cos \gamma_C)} (W_{TOT} \cos \gamma_C - P_Y) \qquad (63)$$

Let

$$C_1 = \frac{1}{\mu \cos \gamma_C - \sin \gamma_C} \qquad (64)$$

$$C_2 = \frac{1}{\mu \sin \gamma_C + \cos \gamma_C} \qquad (65)$$

Substitute EQ 64 and 65 into 63,

$$C_1 (P_X - W_{TOT} \sin \gamma_C) = C_2(W_{TOT} \cos \gamma_C - P_Y) \qquad (66)$$

$$W_{TOT} (C_1 \sin \gamma_C + C_2 \cos \gamma_C) = C_1 P_X + C_2 P_y \qquad (67)$$

Let

$$C_3 = \frac{1}{C_1 \sin \gamma_C + C_2 \cos \gamma_C} \qquad (68)$$

Substitute EQ 68 into 67

$$W_{TOT} = C_3(C_1P_X + C_2P_Y) \tag{69}$$

Or

$$P_X = \frac{W_{TOT}}{C_3C_1} - \frac{C_2}{C_1}P_Y \tag{70}$$

From EQ 62 and 69

$$C_3(C_1P_X + C_2P_y) = \frac{1}{\eta_{CG} \cos \varphi}(P_YL - P_Xb) \tag{71}$$

Let

$$C_4 = \eta_{CG} \cos \varphi \tag{72}$$

Then, From EQ 71 and 72

$$C_1P_X + C_2P_Y = \frac{1}{C_3C_4}(P_YL - P_Xb) \tag{73}$$

$$P_X(C_1 + \frac{b}{C_3C_4}) = P_Y(\frac{L}{C_3C_4} - C_2) \tag{74}$$

$$P_X = P_Y(\frac{L - C_2C_3C_4}{b + C_1C_3C_4}) \tag{75}$$

Let

$$C_5 = \frac{L - C_2C_3C_4}{b + C_1C_3C_4} \tag{76}$$

Then, From EQ 70 and 75

$$C_5P_Y = \frac{W_{TOT}}{C_3C_1} - \frac{C_2}{C_1}P_Y \tag{77}$$

And

$$P_Y = \frac{W_{TOT}}{C_3(C_1C_5 + C_2)} \tag{78}$$

$$R_A = C_2 (W_{TOT} \cos \gamma - P_Y) \qquad (79)$$

$$P_X = \frac{R_A}{C_1} + W_{TOT} \sin \gamma_C \qquad (80)$$

For $\gamma_C = 27.2^0$ and $\mu = 0.2$

$$C_1 = \frac{1}{\mu \cos \gamma_C - \sin \gamma_C} = -3.582 \qquad (81)$$

$$C_2 = \frac{1}{\mu \sin \gamma_C + \cos \gamma_C} = 1.020 \qquad (82)$$

$$C_3 = \frac{1}{C_1 \sin \gamma_C + C2 \cos \gamma_C} = -1.369 \qquad (83)$$

$$C_4 = \eta_{CG} \cos \varphi = f_1(W_{TOT}) \qquad (84)$$

$$C_5 = \frac{20.5 + 1.396\, C_4}{5.17 + 4.904\, C_4} = f_2\,(W_{TOT}) \qquad (85)$$

Substituting, EQ 78, 79 and 80 Become

$$P_Y = \frac{W_{TOT}}{4.904 C_5 - 1.396} \qquad (86)$$

$$R_A = 0.907\, W_{TOT} - 1.02\, P_Y \qquad (87)$$

$$P_X = -0.279\, R_A + 0.457\, W_{TOT} \qquad (88)$$

Solutions to EQ 86, 87 and 88 are plotted in Figure 17. Again, μ=0.2. Also shown in Figure 17 are the shapes of the Shear and Bending Moment diagrams.

EQ 89 is an expression for the Maximum Bending Moment.

$$M_{MAX} = R_A(\cos \gamma_C + \mu \sin \gamma_C)(X_M) + R_A(\mu \cos \gamma_C - \sin \gamma_C)(Y_{HA})$$

$$- \frac{X_M}{L_C}(W_{TOT} - W_H) \left[\frac{X_M}{2} \cos \gamma_C - (Y_{HA} - Y'_{CG}) \sin \gamma_C\right] \qquad (89)$$

$$= R_A \left(\frac{X_M}{C_2} + \frac{2.21}{C_1}\right) - \frac{X_M}{L_C} (W_{TOT} - W_H) \left[\frac{X_M}{2} \cos \gamma_C - (2.21 - Y'_{CG}) \sin \gamma_C\right] \qquad (90)$$

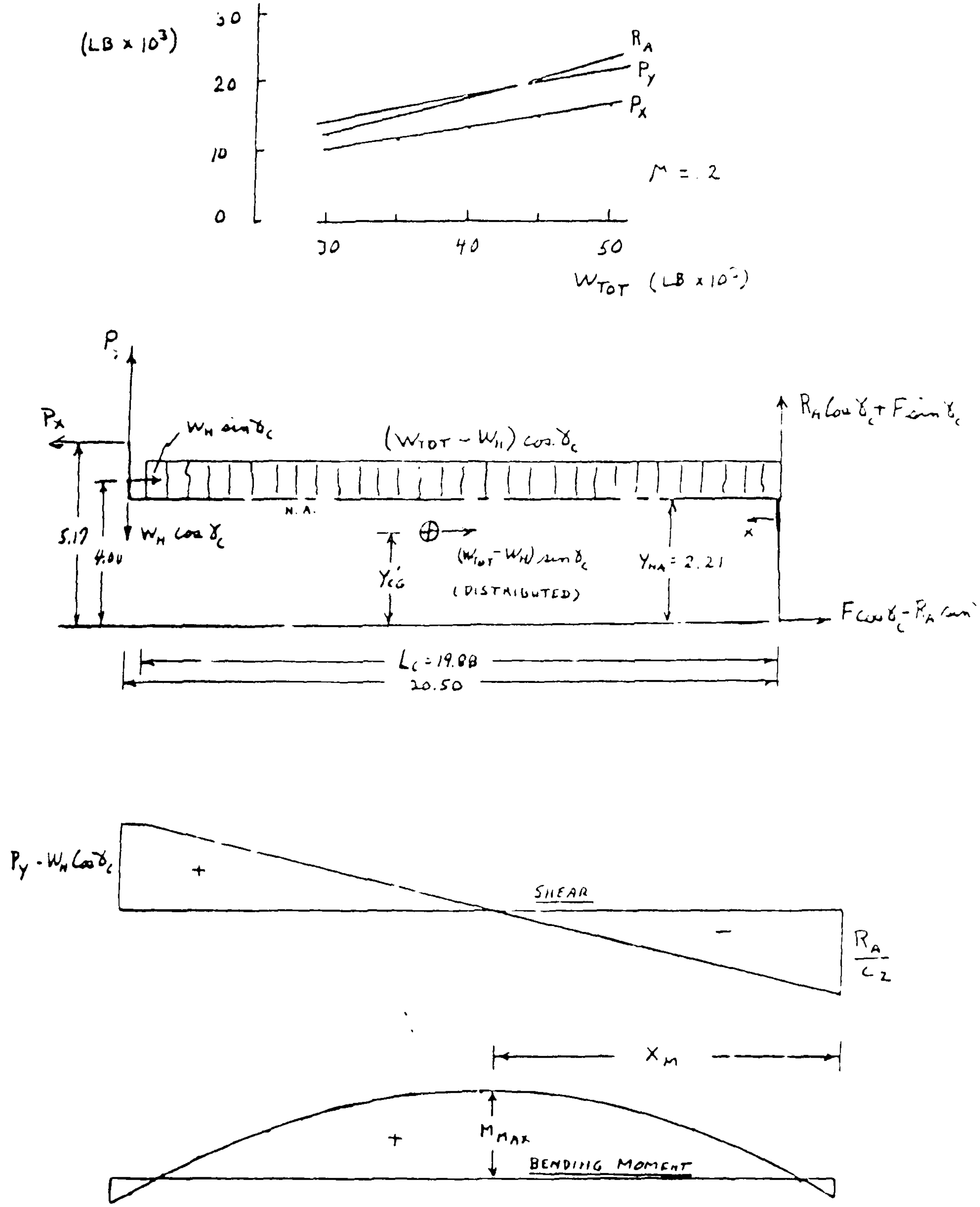


Figure 17. Condition 2, Force and Bending Moment Distribution

Note that Y'_{CG} and X_M are a function of the total weight condition. These functions are evaluated as follows:

$$Y'_{CG} = \frac{2.90(W_C) + \left(\frac{W_P}{12167} + 0.54\right) W_P}{W_C + W_P} \qquad (91)$$

$$X_M = \frac{R_A/C_2\,(L_C)}{(P_Y - W_H \cos \gamma_C) + R_A/C_2} \qquad (92)$$

EQ 91 and 92 are plotted in Figures 18 and 19 respectively. EQ 90 is plotted in Figure 20.

The maximum stress in the longitudinal beams is estimated as follows: (Refer to EQ 42 and 45).

$$\sigma MAX_U = -\frac{M_{MAX}}{30.69} + \frac{L_X}{15.69} \qquad (93)$$

$$\sigma MAX_L = \frac{M_{MAX}}{26.91} + \frac{L_X}{6.11} \qquad (94)$$

Where:

$$L_X = \frac{R_A}{C_1} + \frac{X_M}{L_C}(W_{TOT} - W_H) \sin \gamma_C \qquad (95)$$

The Maximum Shear Stress in the side walls in estimated as follows: (Refer to EQ 48).

$$\tau MAX = \frac{P_Y - W_H \cos \gamma_C}{5.31} \qquad (96)$$

Equations 93, 94 and 96 are plotted in Figure 21.

For WTOT = 44,800 LB, the following safety factors (FS) are computed:

$$FS_U = \frac{30000}{2164} = 13.86 \text{ (Upper Beam)} \qquad (97)$$

$$FS_L = \frac{30000}{2761} = 10.87 \text{ (Lower Beam)} \qquad (98)$$

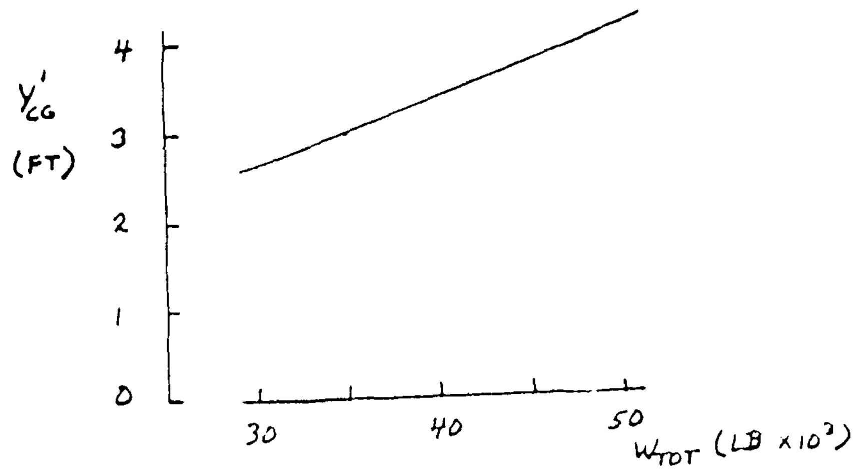


Figure 18. Container-Plus-Payload Center of Gravity

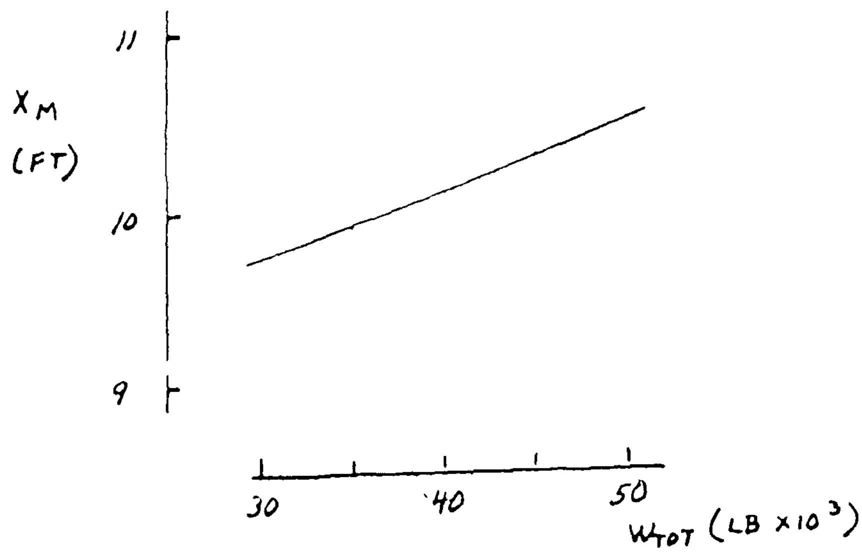


Figure 19. Location of Maximum Bending Moment

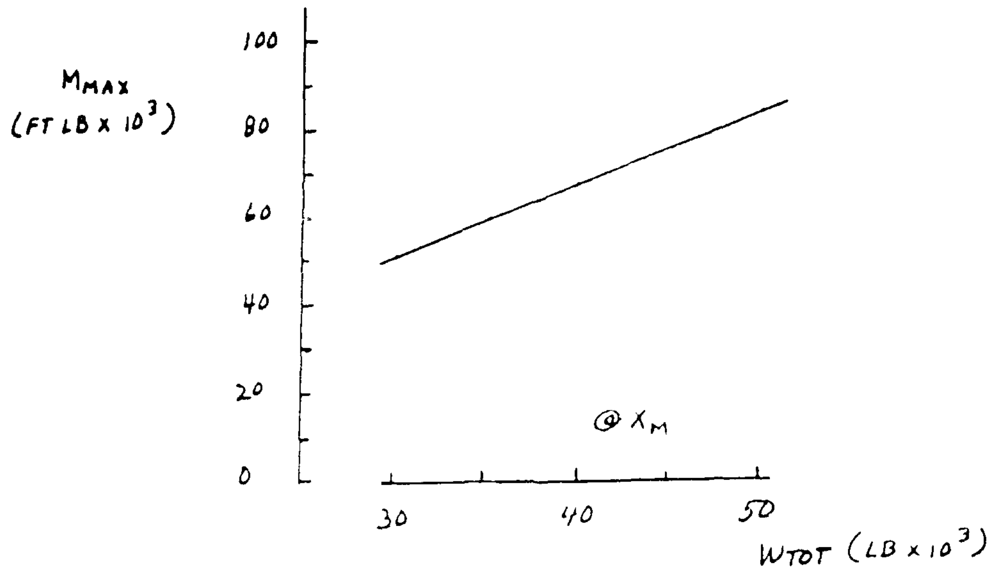


Figure 20. Condition 2, Maximum Bending Moment

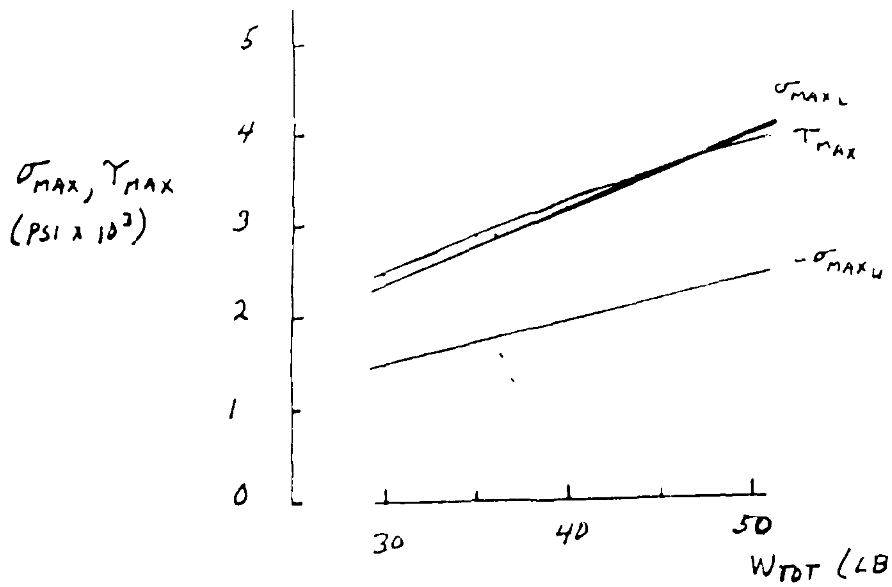


Figure 21. Condition 2, Maximum Stress

$$FS_W = \frac{20000}{3516} = 5.69 \text{ (Side Wall)} \tag{99}$$

6.3 Condition 3 - Initial Movement of the container onto the PLS Vehicle.

This condition is examined to determine the container loading conditions as the container starts its movement onto the PLS vehicle. At this point, the container is tilted at an angle of 27.2 degrees, and the bottom beams of the container are supported by the PLS vehicle. The support points are 10.39 feet from the door end of the container. The forces being exerted on the container are noted in Figure 22. Based on this load distribution, the following equations can be written:

$$\Sigma F_X = P_X - F - W_{TOT} \sin \gamma_C = 0 \tag{100}$$

$$\Sigma F_Y = P_Y + R_D - W_{TOT} \cos \gamma_C = 0 \tag{101}$$

$$\Sigma M_D = -W_{TOT} (\eta_{CG}) \sin \varphi + P_X b - P_Y (L - L_D) = 0 \tag{102}$$

$$F = \mu R_D \tag{103}$$

From EQ 100

$$P_X = \mu R_D + W_{TOT} \sin \gamma_C \tag{104}$$

From EQ 101

$$P_Y = -R_D + W_{TOT} \cos \gamma_C \tag{105}$$

From EQ 102

$$W_{TOT}(\eta_{CG}) \sin \varphi = P_X b - P_Y (L - L_D) \tag{106}$$

From EQ 104 and 105

$$R_D = \frac{P_X}{\mu} - \frac{W_{TOT}}{\mu} \sin \gamma_C = W_{TOT} \cos \gamma_C - P_Y \tag{107}$$

$$W_{TOT} \left(\cos \gamma_C + \frac{\sin \gamma_C}{\mu}\right) = \frac{P_X}{\mu} + P_Y \tag{108}$$

$$W_{TOT} = \frac{1}{\mu \cos \gamma_C + \sin \gamma_C} (P_X + \mu P_Y) \tag{109}$$

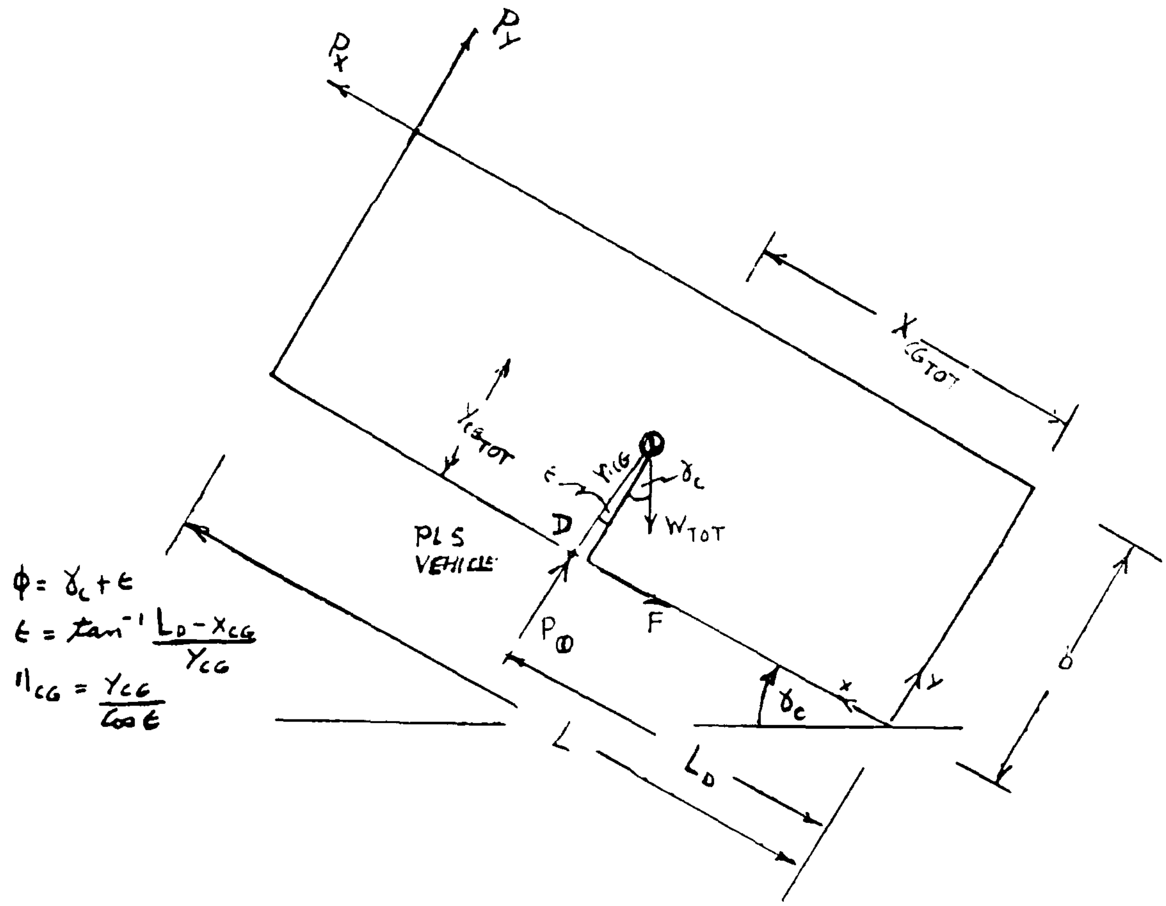


Figure 22. Condition 3, External Loads

Let $$C_6 = \frac{1}{\mu \cos \gamma_c + \sin \gamma_c} \quad (110)$$

Then

$$W_{TOT} = C_6(P_X + \mu P_Y) \quad (111)$$

$$P_X = \frac{W_{TOT}}{C_6} - \mu P_Y \quad (112)$$

From EQ 106 and 111

$$C6(P_X + \mu P_Y) = \frac{1}{\eta_{CG} \sin \varphi} [P_X b - P_Y (L - L_D)] \quad (113)$$

Let

$$C_7 = \frac{1}{\eta_{CG} \sin \varphi} \quad (114)$$

$$L'_D = L - L_D \quad (115)$$

Then

$$C_6(P_X + \mu P_Y) = C_7[P_X b - P_Y L'_D] \quad (116)$$

$$P_X (C_6 - C_7 b) = - P_Y (C_7 L'_D + C_6 \mu) \quad (117)$$

$$P_X = - P_Y \left(\frac{C_7 L'_D + C_6 \mu}{C_6 - C_7 b}\right) \quad (118)$$

From 112 and 118

$$- P_Y \left(\frac{C_7 L'_D + C_6 \mu}{C_6 - C_7 b}\right) = \frac{W_{TOT}}{C_6} - \mu P_Y \quad (119)$$

Let

$$C_8 = \frac{C_7 L'_D + C_6 \mu}{C_6 - C_7 b} \quad (120)$$

Then

$$P_Y (\mu - C_8) = \frac{W_{TOT}}{C_6} \quad (121)$$

$$\left.\begin{aligned} P_Y &= \frac{W_{TOT}}{C_6\,(\mu - C_8)} && (122)\\ R_D &= W_{TOT}\cos\gamma_C - P_Y && (123)\\ P_X &= \mu R_D + W_{TOT}\sin\gamma_C && (124) \end{aligned}\right\}$$

For $\gamma_C = 27.2^o$ and $\mu = 0{,}2$

$$C_6 = \frac{1}{\mu\cos\gamma_C + \sin\gamma_C} = 1.575 \qquad (125)$$

$$C_7 = \frac{1}{\eta_{CG}\sin\varphi} = f_3\,(W_{TOT}) \qquad (126)$$

$$L'_D = L - L_D = 20.5 - 10.39 = 10.110 \qquad (127)$$

$$C_8 = \frac{10.11\,C_7 + 0.315}{1.575 - 5.17\,C_7} = f_4\,(W_{TOT}) \qquad (128)$$

Substituting, EQ 122, 123 and 124 become

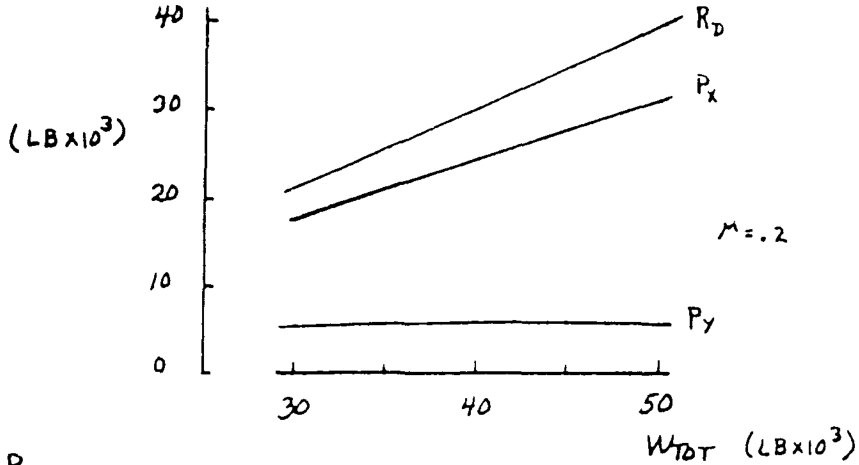
$$\left.\begin{aligned} P_Y &= \frac{W_{TOT}}{0.315 - 1.575\,C_8} && (129)\\ R_D &= 0.889\,W_{TOT} - P_Y && (130)\\ P_X &= 0.2R_D + 0.457\,W_{TOT} && (131) \end{aligned}\right\}$$

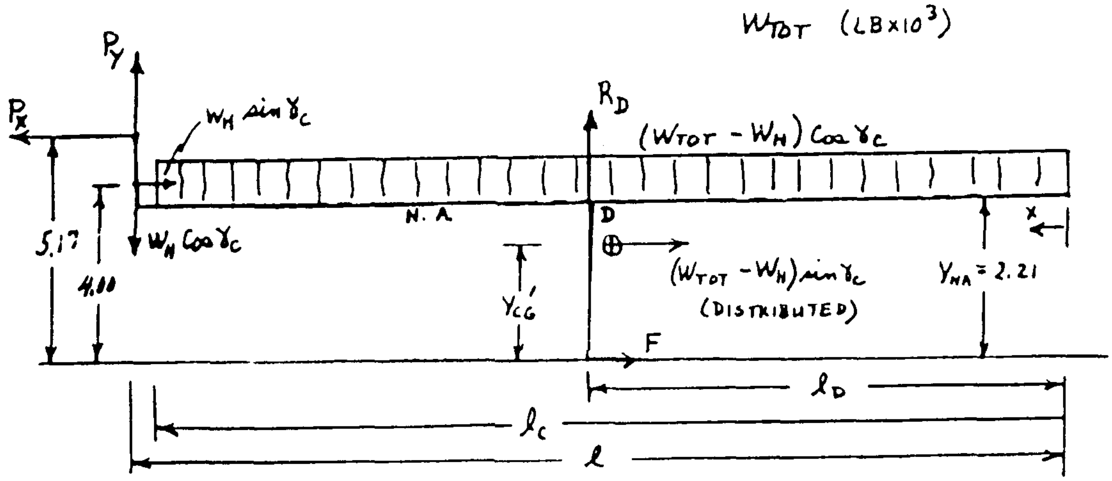
Solutions to EQ 129, 130 and 131 are plotted in Figure 23. Again, $\mu = 0.2$. Also shown in Figure 23 are the shapes of the Shear and Bending Moment diagrams.

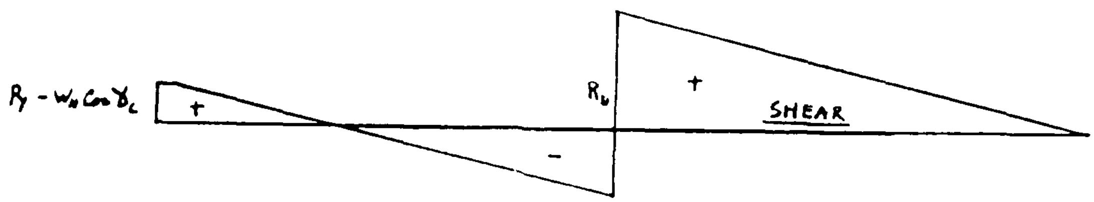
Following is an expression for the Maximum Bending Moment (to the right of Point D):

$$M_{MAX} = \frac{L_D}{L_C}(W_{TOT} - W_H)\,[\,(Y_{NA} - Y'_{CG})\sin\gamma_C - \frac{L_D}{2}\cos\gamma_C] \qquad (132)$$

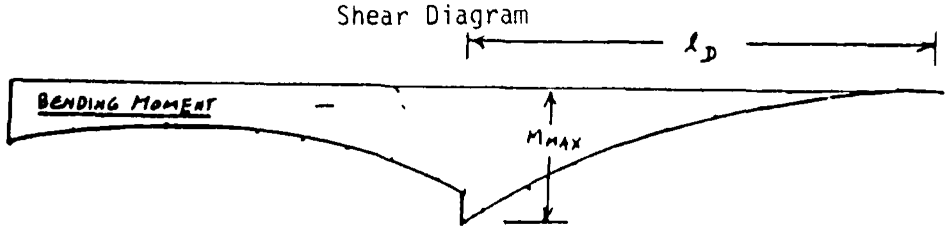
NOTE: Y'$_{CG}$ is defined in EG 91. EQ 132 is plotted in Figure 24. Also plotted in Figure 24 is the Bending Moment to the left of Point D (M'$_D$). M'$_D$ is defined as follows:







Shear Diagram



Bending Moment Diagram

Figure 23. Condition 3, Force and Bending Moment Distribution

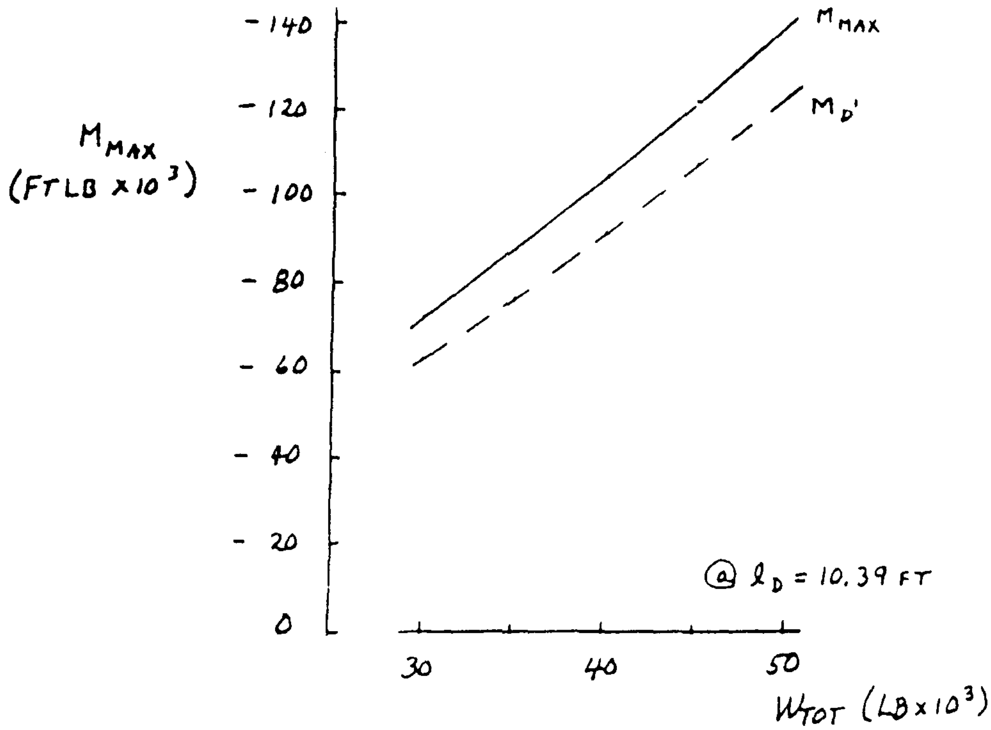


Figure 24. Condition 3, Maximum Bending Moment

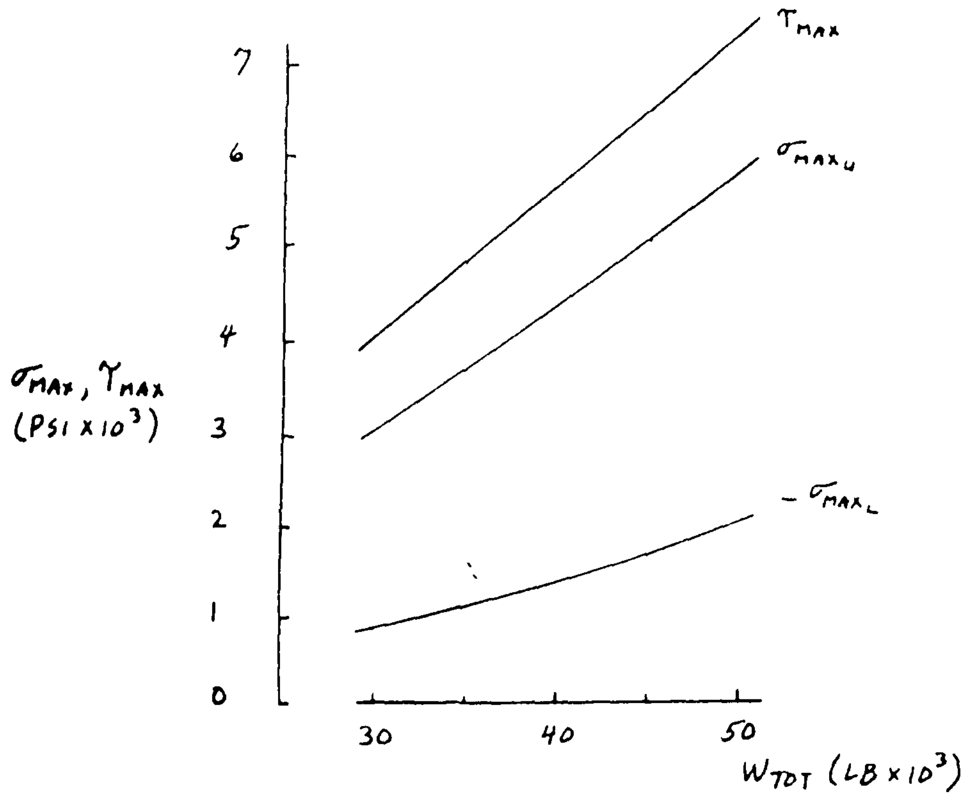


Figure 25. Condition 3, Maximum Stress

$$M'_D = M_{MAX} + \mu R_D (Y_{NA}) \tag{133}$$

The maximum stress in the longitudinal beams is estimated as follows: (Refer to 93 and 94).

$$\sigma_{MAX_U} = -\frac{M_{MAX}}{30.69} + \frac{L_X}{15.69} \tag{93'}$$

$$\sigma_{MAX_L} = \frac{M_{MAX}}{26.91} + \frac{L_X}{6.11} \tag{94'}$$

Where:

$$L_X = \mu R_D + \frac{L_D}{L_C} (W_{TOT} - W_H) \sin \gamma_C \text{ (Conservative)} \tag{134}$$

The maximum shear stress in the side walls is estimated as follows: (Refer to EQ 48).

$$\tau_{MAX} = \frac{R_D}{5.31} \tag{135}$$

Equations 93', 94' and 135 are plotted in Figure 25.

For W_{TOT} = 44,800 LB, the following Safety Factors (FS) are computed:

$$FS_U = \frac{30000}{5041} = 5.95 \text{ (Upper Beam)} \tag{136}$$

$$FS_L = \frac{30000}{1667} = 18.00 \text{ (Lower Beam)} \tag{137}$$

$$FS_W = \frac{20000}{6461} = 3.10 \text{ (Side Wall)} \tag{138}$$

For comparison, Equation 139 is solved considering the container structure to function like a PLS flatrack. In other words, the Upper Longitudinal Beam is considered to be ineffective. For this situation,

$$Y_{NA} = 5.49 \text{ IN} = 0.458 \text{ FT} \tag{139}$$

The results are plotted in Figure 26.

The maximum stresses are estimated as follows:

$$\sigma_{MAX_U} = -\frac{M_{MAX}}{I_{TOT}} C_U + \frac{L_X}{2A_L} \tag{140}$$

$$= -\frac{M_{MAX}\,(5.52)(12)}{2(20.5)} + \frac{L_X}{2(2.24)} \tag{141}$$

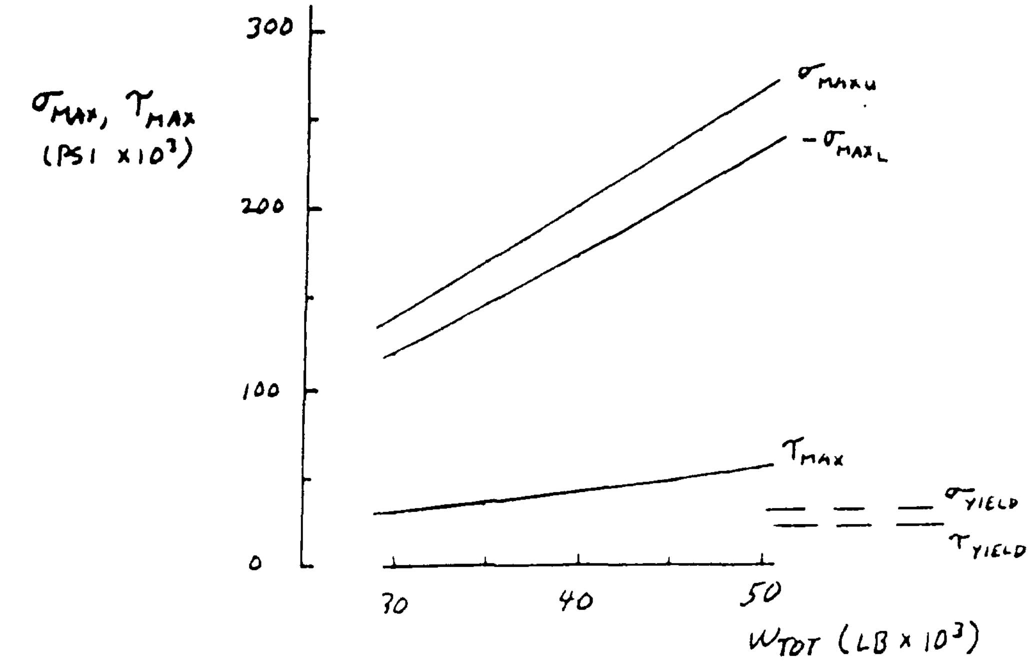


Figure 26. "Lower Beam Only", Maximum Bending Moment

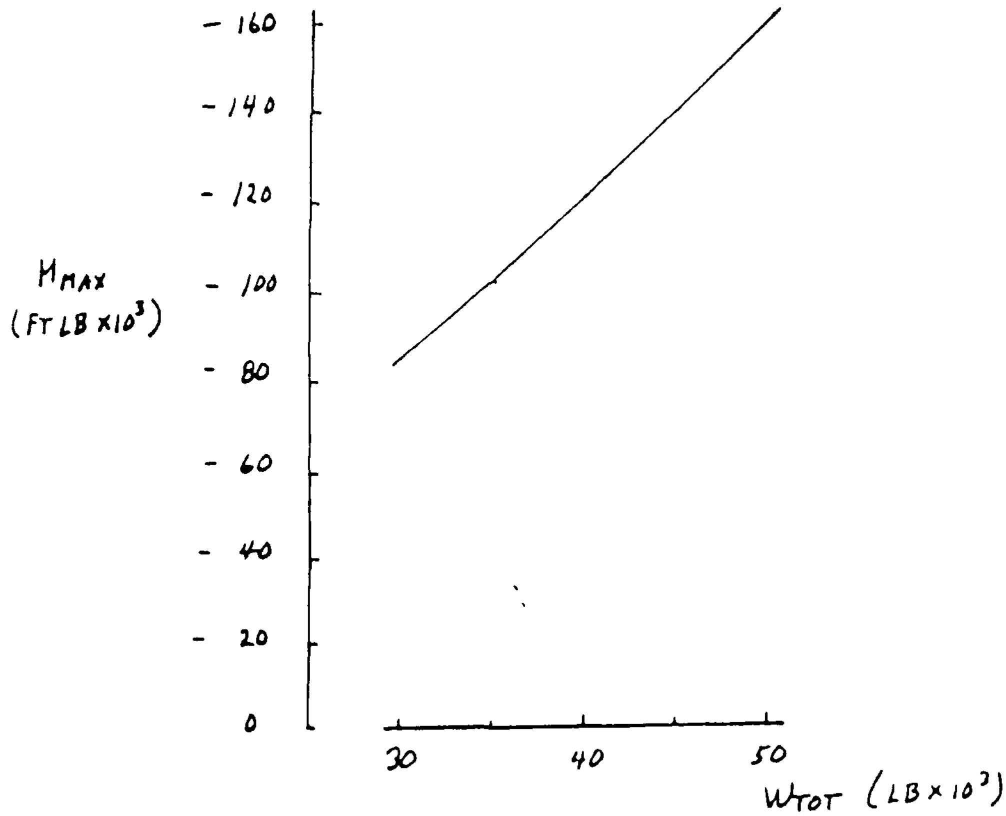


Figure 27. "Lower Beam Only", Maximum Stress

$$= -\frac{M_{MAX}}{0.619} + \frac{L_X}{4.48} \tag{142}$$

$$\sigma_{MAX_L} = \frac{M_{MAX}\, C_L}{I_{TOT}} + \frac{L_X}{2A_L} \tag{143}$$

$$= \frac{M_{MAX}\,(4.99)(12)}{2(20.5)} + \frac{L_X}{4.48} \tag{144}$$

$$= \frac{M_{MAX}}{0.685} + \frac{L_X}{4.48} \tag{145}$$

From EQ 46:

$$\tau_{MAX} = \frac{R_D(0.18 \times 5.52^2 \times 0.5)2}{2(20.5)(0.18)} \tag{146}$$

$$= \frac{R_D}{0.743} \tag{147}$$

The results are plotted in Figure 27. As is expected, the stresses so computed far exceed stress allowables.

7.0 CONTAINER/PLS SLIDING CONTACT INTERFACE

The point where the container makes contact with the HIK sliding mechanism on the PLS vehicle is a stress concentration area on the container. Care must be taken to ensure that the reactive load R_D is adequately distributed by an "area" contact, as opposed to a "point" contact. At a total weight condition of 50,000 pounds, this load is approximately 20,000 pounds on each lower longitudinal beam. For the Fruehauf container, the minimum area of contact for each beam is estimated as follows:

ASSUME: Allowable Bearing Pressure (P_B) = 20,000 PSI, and FS = 2

$$\text{Bearing Area} = FS\left(\frac{\text{Load}}{P_B}\right)$$

$$= 2\left(\frac{20000}{20000}\right)$$

$= 2$ in^2 or 4 in length for a 0.5 in wide Flange

It appears that the HIK sliding mechanism design can provide this degree of contact if properly designed.

8.0 CONCLUSIONS

There appears to be adequate factors of safety associated with transferring a 8'x8'x20' ANSI/ISO container from the ground to the bed of a PLS vehicle via a HIK. However, there is a concern about the effectiveness of the HIK sliding mechanism in distributing the reactive load from the PLS vehicle over a sufficient bearing area. Care must be taken to distribute the reactive load and avoid "point" contact.

Another approach to evaluating the adequacy of the ISO container structural design for the HIK type operation is to examine the acceptance test requirements, as presented in ISO 1496/1 and summarized in Appendix A. Operationally, the HIK concept subjects the container to a transverse torque as the container is pulled onto the PLS vehicle. This type of loading is similar to Test No. 10, which calls for a torque of 134,800 ft lbs. The foregoing analysis yields the following values for the HIK operation:

WTOT	TORQUE	FS
30,000	52,278	2.58
40,000	70,861	1.90
44,800	79,928	1.69
50,000	89,828	1.50

Again, these Factors of Safety are considered adequate.

An area of concern is the blocking and bracing of the ammo load in the container. Steps should be taken to ensure that the load cannot slide and end up being supported by the door-end of the container, as one end is lifted onto the PLS vehicle. The container is acceptance tested to resist a distributed load on the door-end equal to .4 of its design payload. For the Fruehauf design, this door-end load is 16,338 pounds. An ammo load of 32,700 pounds, tilted at 30 degrees (2.8 degrees greater than the 27.2 degrees estimated for the loading operation) and free to slide, will yield this magnitude of load.

ISO containers that were observed in on-site inspections appeared to utilize steel in both the upper and the lower longitudinal beams. As can be noted in Appendix C, such containers exibit cross section properties that are more robust than those of the Fruehauf container. Therefore, the conclusions relative to the Fruehauf container are considered to be generally applicable to the general class of ISO containers.

MILVAN cargo containers are, in general, more rugged than ANSI/ISO containers. This is evident in their respective tare weights. For example, the Fruehauf container tare weight is 3955 pounds, whereas the tare weight for a comparable Type I MILVAN is spec'd at approximately 4700 pounds. Also, the door-end of this type of MILVAN is acceptance tested to a distributed load of 33,280 pounds, compared to a 16,338 pound load for the Fruehauf container. Type II MILVANs, with mechanical restraint systems, appear to be of more rugged design than Type I MILVANs. Hence, the structural stresses on both types should be less severe than the stresses on ANSI/ISO containers during a HIK loading operation.

9.0 RECOMMENDATIONS

Based on the foregoing analysis, the following recommendations are made:

1) Proceed with the planned evaluation test of the HIK concept. (The Safety Factor appears to be adequate up to the container's maximum gross weight of 44,800 pounds.)

2) Ensure that the ammo load is prevented from sliding as the container is tilted during the HIK loading operation.

3) Place special focus on evaluating the effectiveness of the HIK sliding mechanism in distributing the reactive load from the PLS vehicle.

4) Include a "narrow flange" container, such as the Fruehauf design, in the evaluation test program.

5) After the container is loaded onto the PLS vehicle by the HIK, the container must be secured for road travel. It is recommended that under this condition the container be rigidly supported on the PLS vehicle by the container's four lower corner fittings. In the description of the HIK design concept, it is not clear how this will be accomplished. Therefore, this should be a point of special focus during the HIK evaluation tests.

6) During the evaluation testing of the HIK loading operation, monitor the stress levels across the container cross section at the longitudinal station where the container lower beam makes contact with the PLS vehicle. (In the analysis presented in this report, this station was determined to be 10.39 feet from the door-end.) It is recommended that strain gages be placed at approximately two foot intervals across one of the side walls. (Do not exceed limit stress levels of 30,000 psi (normal) and 20,000 psi (shear)).

7) Place special focus on the "fork lift' slots in the base of the container during the HIK loading operation. Ensure that load is adequately distributed over this region to avoid bending of the bottom flange.

APPENDIX A

EXCERPTS

ISO 1496/1 Series 1 freight containers - Specification and testing - Part 1: General cargo containers for general purposes.

sions equal to those of the internal cross-section of the containers, and, in any case, not less than 2 261 mm[1] high, and 2 286 mm[1] wide.

4.8 Requirements — Optional features

4.8.1 Fork-lift pockets

4.8.1.1 Fork-lift pockets used for handling 1CC, 1C, 1CX, 1D and 1DX containers in the loaded or unloaded condition may be provided as optional features.

Fork-lift pockets shall not be provided on 1AA, 1A, 1AX, 1BB, 1B and 1BX containers.

4.8.1.2 Where a set of fork-lift pockets has been fitted as in 4.8.1.1, a second set of fork-lift pockets may, in addition, be provided on 1CC, 1C and 1CX containers for empty handling only.

4.8.1.3 The fork-lift pockets, where provided, shall meet the dimensional requirements specified in annex C and shall pass completely through the base structure of the container so that lifting devices may be inserted from either side. It is not necessary for the base of the fork-lift pockets to be the full width of the container but it shall be provided in the vicinity of each end of the fork pockets.

4.8.2 Grappler arms or similar devices

Fixtures for handling all containers by means of grappler arms or similar devices may be provided as optional features. The dimensional requirements for such fixtures are specified in annex D.

4.8.3 Gooseneck tunnels

Gooseneck tunnels may be provided as optional features in containers 1AA, 1A and 1AX. The dimensional requirements are specified in annex E and, in addition, all other parts of the base structure shall be as specified in 4.3.

5 Testing

5.1 General

Unless otherwise stated, containers complying with the design requirements specified in clause 4 shall, in addition, be capable of withstanding the tests specified in 5.2 to 5.14 inclusive, as applicable. Containers shall be tested in the condition in which they are designed to be operated. Also, containers equipped with removable structural items shall be tested with these items in position. It is recommended that the test for weatherproofness (test No. 13) be carried out last.

5.1.1 The symbol P denotes the maximum payload of the container to be tested, that is,

$$P = R - T$$

where

R is the rating;

T is the tare.

NOTE — R, P and T, by definition, are in units of mass. Where test requirements are based on the gravitational forces derived from these values, those forces, which are inertial forces, are indicated thus :

Rg, Pg, Tg

the units of which are in newtons or multiples thereof.

The word "load", when used to describe a physical quantity to which units may be ascribed, implies mass.

The word "loading", for example, as in "internal loading", implies force.

5.1.2 The test loads or loadings within the container shall be uniformly distributed.

5.1.3 The test load or loading specified in all of the following tests are the minimum requirements.

5.1.4 The dimensional requirements to which reference is made in the requirements sub-clause after each test are those specified in :

a) the dimensional and design requirement clauses of this part of ISO 1496;

b) ISO 668;

c) ISO 1161.

5.2 Test No. 1 — Stacking

5.2.1 General

This test shall be carried out to prove the ability of a container to support five other fully loaded containers of the same length and rating under the acceleration conditions encountered in ships' cell structures, taking into account relative eccentricities between containers due to clearance.

5.2.2 Procedure

The container shall be placed on four level pads, one under each bottom corner fitting.

The pads shall be centralized under the fittings and shall be substantially of the same plan dimensions as the fittings. The

1) 2 261 mm = 7 ft 5 in
2 286 mm = 7 ft 6 in

Annex A

Diagrammatic representation of capabilities appropriate to all types and sizes of general purpose containers, except where otherwise stated

NOTES

1 The externally applied forces shown below are for one end or one side only. The loads shown within the containers represent uniformly distributed internal loads only, and such loads are for the whole container.

2 The figures in this annex correspond to the tests described in 5.2 to 5.13 only where marked.

3 For definitions of *R*, *P*, and *T*, see 5.1.1.

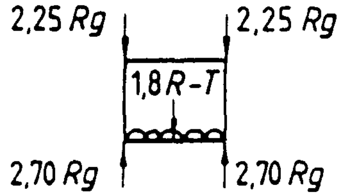
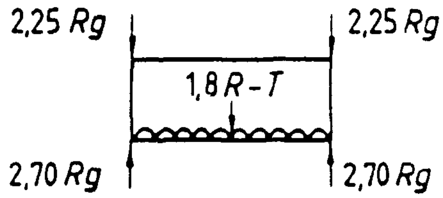
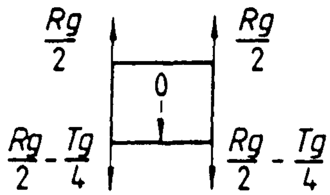
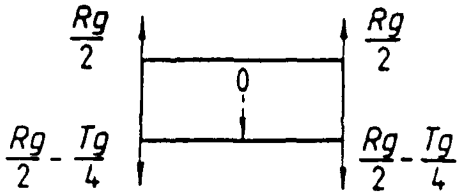
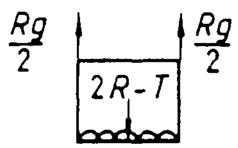
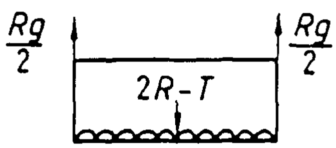
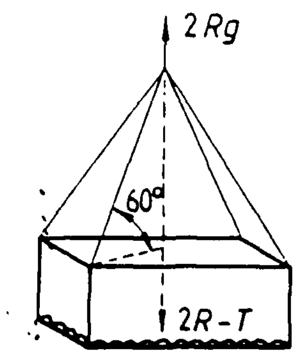
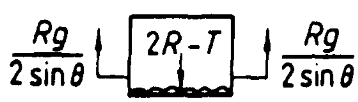
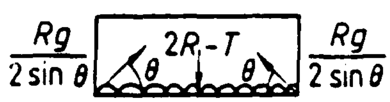
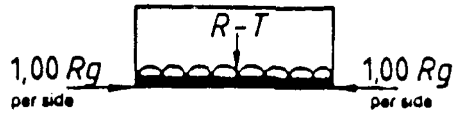
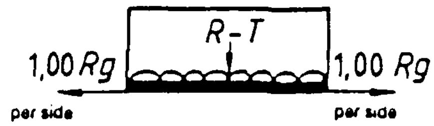
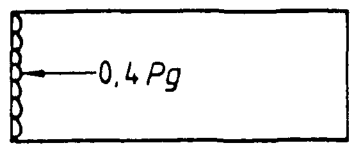
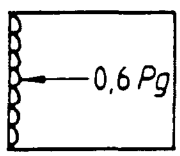
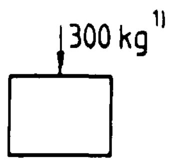
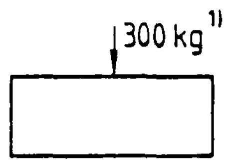
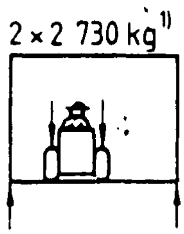
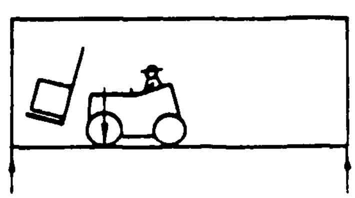
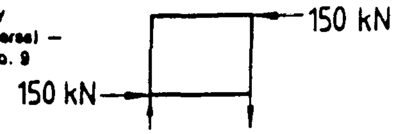
Figure No.		End elevations	Side elevations
1	Stacking – Test No. 1		
2	Top lift		
3	Top lift – Test No. 2	 Not applicable to 1D and 1DX containers	
3A	Top lift – Test No. 2	 Applicable to 1D and 1DX containers only	
4	Bottom lift – Test No. 3		

Figure No.	End elevations	Side elevations
5	Restraint (longitudinal) – Test No. 4	
6		
7	End loading – Test No. 5	
8	Side loading – Test No. 6 	
9	Roof load – Test No. 7 	
	Applicable where a rigid roof is provided	
10	Wheel loads Test No. 8 	

1) 300 kg = 660 lb
2 × 2 730 kg = 2 × 6 000 lb

<table>
<tr><th>Figure No.</th><th>End elevations</th><th>Side elevations</th></tr>
<tr><td>11</td><td>Rigidity (transverse) — Test No. 9
</td><td rowspan="6">Not applicable to 1D and 1DX containers</td></tr>
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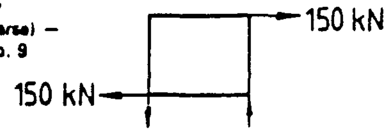
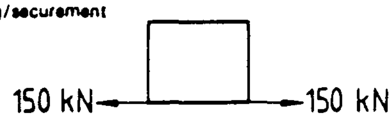
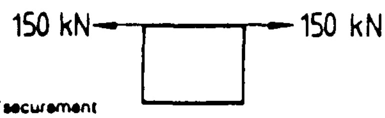
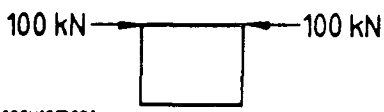
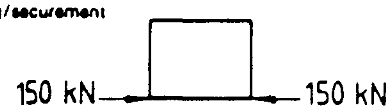
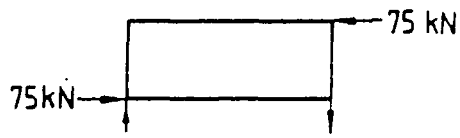
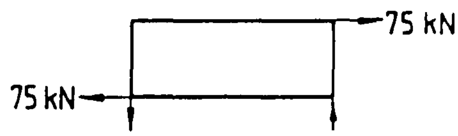
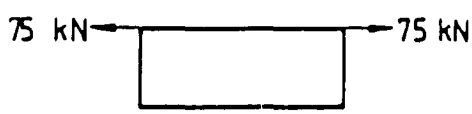
</td></tr>
<tr><td>13</td><td>Lashing/securement
</td></tr>
<tr><td>14</td><td>
Lashing/securement</td></tr>
<tr><td>15</td><td>
Lashing/securement</td></tr>
<tr><td>16</td><td>Lashing/securement
</td></tr>
<tr><td>17</td><td rowspan="2">Rigidity (longitudinal) — Test No. 10
Not applicable to 1D and 1DX containers</td><td></td></tr>
<tr><td>18</td><td></td></tr>
<tr><td>19</td><td>Lashing/securement
(This type of loading is inadmissible except as applied in 3A.)</td><td></td></tr>
<tr><td>20</td><td>Lashing/securement
Not applicable to 1D and 1DX containers</td><td></td></tr>
</table>

APPENDIX B

FRUEHAUF CONTAINER - GENERAL SPECIFICATION

GENERAL SPECIFICATIONS

KA2-20

1. CORNER FITTINGS - ANSI/ISO corner fittings are installed at each corner with the distance between the top face of the corner fittings and the roof sheet to be 1/4' minimum. The distance between the bottom face of the lower corner fittings and any other part of the container is to be 1/2' nominal.

2. FRONT WALL - Front corner posts are two-piece sections. The upper rail is a one-piece and the lower rail is a three-piece section welded continuously, to form an integral structure with the upper and lower corner fittings to achieve a single frame weldment prior to installation. Sections are fabricated from low alloy, high strength steel material. Additionally, the steel upper rail (#10 gauge) extended 15" inward full width, providing an area to prevent roof damage due to the spreader lifting lugs. Four aluminum hat-shaped intermediate wall posts rivited to 0.063 prepainted aluminum outer panels. All lap joints between sheets and area between sheets and fabricated sections are sealed to prevent water entry.

3. SIDE WALL - Prepainted, 0.063 aluminum flat panels with extruded aluminum hat-shaped body posts on 24' centers. Upper rails extruded aluminum - lower rails 7 gauge high strength steel formed rolled sections. All lap joints between sheets and area between sheets and rails are sealed to prevent water entry.

4. REAR FRAME - Rear corner posts are 45,000 psi yield high strength fabricated two piece - 1/4" thick steel with lock flange providing rear door hinge and hardware protection - 1/4' one-piece channel shaped crossmember and a two-piece header section welded continuously to form an integral structure with the upper and lower corner fittings to achieve a single frame weldment prior to installation. Header and crossmember sections are fabricated from low alloy high strength steel material. As in the case of the front, the steel roof cap (10 gauge) extends 15" inward full width to prevent roof damage due to the lifting lugs. Provisions for water drainage is handled at the sides and not over the door area.

5. REAR DOORS - 1" thick pre-gasketed solid plymetal double doors - 0.050 prepainted aluminum exterior panel with 0.050 aluminum interior panel bonded to the plywood core. (1) Extruded aluminum hat-shape section reinforcement with steel end plates per door to engage rack pins on header and crossmember - (2) Heavy-duty lock rods with zero torque cams per door. (3) Heavy-duty hinges per doors with stainless steel pins - steel hardware sections hot-dipped galvanized. Exterior double contact gaskets are extruded polyvinyl chloride.

6. ROOF - One-piece full width 0.050 aluminum sheet tension flattened prior to installation - extruded aluminum "I" beam sections spaced on 24" centers bonded to the roof panel - design allows the roof sheet to be attached with solid fasteners outside of the cargo area and sheet is sealed watertight.

7. CROSSMEMBERS - High strength steel "I" beam section, 4-7/8" deep spaced on 15" centers.

8. FLOOR - 1-1/8" thick ship-lap laminated hardwood floor is secured with (3) 5/16" dia. screws per board per crossmember.

9. LINING - 1/4" exterior grade plywood, fastened in compliance with T.I.R. requirements on the front and sidewalls.

* * PAINT - Side wall and outer door panels pre-painted aluminum color, utilizing Fruehauf exclusive 2-coat paint system - end frames and steel rails primed with zinc grey primer and top coat. Frames and rails are shot-blast cleaned prior to coating. Aluminum side rails natural aluminum.

UNDERCOATING - All exposed under-surfaces of wood and steel coated approximately 15 mils thick with Tectyl 121-B.

CAULKING - All exterior areas are sealed to prevent entry of water.

TAPE - In all cases where dissimilar metals may contact, are protected from galvanic corrosion by usage of electrolytically insulated tape.

PERFORMANCE SPECIFICATIONS

Container is constructed to meet the following standards or requirements applicable as of date of manufacture:

A.N.S.I./I.S.O., C.S.C., T.I.R.

A.B.S. will be used as the certifying agency.

Customer furnished I.S.O. unit numbers will be installed.

APPENDIX C

ESTIMATION OF CROSS SECTION PROPERTIES

1.0 Estimation Of Cross Section Properties For Fruehauf Container.

1.1. Neutral Axis and Moment of Inertia (Box Structure).

Assume the Bending Moment Stress in the box beam structure is carried in the upper and lower longitudinal beam members. (Refer to Figs. 4 and 5.) Note that the upper beam is aluminum ($E \approx 10 \times 10^6$ psi), and the lower beam is steel ($E \approx 30 \times 10^6$ psi). Therefore, the Neutral Axis and Moment of Inertial are estimated as follows:

$$Y_{NA} = \frac{1/3 A_U Y_U + A_L Y_L}{1/3 A_U + A_L}$$

$$= \frac{1/3\ (2.09)(94.2) + 2.24(5.49)}{1/3(2.09) + 2.24} = \underline{\underline{26.53}} \text{ in } (2.21 \text{ ft})$$

$$I_{TOT} \approx [1/3(2.09)(94.20-26.53)^2 + 20.5 + 2.24(26.53-5.49)^2]\ 2$$

$$\approx \{3190 + 20.5 + 992\}\ 2$$

$$\approx \underline{\underline{8405}} \text{ IN}^4$$

NOTE: Stress computed in upper caps should be multiplied by $\frac{1}{3}$. Assume $\tau_{LIMSHEAR}$ = 20,000 psi (Alum).

1.2 Static Moment At Neutral Axis (Box Structure).

$$Q = \{A_L[Y_{HA}-(4.99=0.5)] = (0.021 \times h)\frac{h}{2}\}\ 2$$

$$= \{2.24[26.53 - 5.49] + \frac{0.021}{2}[16.03]2\}\ 2$$

$$= \{ 47.13 + 2.70 \}\ 2$$

$$= \underline{\underline{99.66}} \text{ IN}^3$$

NOTE: Stress computed in "WEB" should be multiplied by $\frac{1}{3}$.

1.3 Section Modulus of Lower Longitudinal Beams.

$$Z = \left(\frac{20.5}{5.52}\right) 2$$

$$= \underline{7.43} \text{ IN}^3$$

2.0 Estimation of Cross Section Properties For Containers Observed During On-Site Inspections.

2.1 Neutral Axis and Moment of Inertia (Box Structure).

Assume Bending Moment Stresses are carried in upper and lower longitudinal beam members. Both beams are of same material. Assume $t_{WALL} = 0.625$ IN. and $\tau_{LIMSHEAR} = 25000$ psi (Steel). (Refer to Figure 5.)

$$Y_{NA} = \frac{A_U Y_U + A_L Y_L + A_W Y_W}{A_U + A_L + A_W}$$

$$= \frac{1.5(93.5) + 1.88(3.5) + 0.0625(85)(42.5+6.5)}{1.5 + 1.88 + 0.0625(85)}$$

$$= \frac{140.25+6.58+260.31}{8.69}$$

$$= \underline{46.85} \text{ IN}$$

$$I_{TOT} = [3.44+1.5(93.5 - 46.85)^2 + 10.13 + 1.88 (46.85 - 3.5)^2 + \frac{0.0625(85)^3}{12} + 0.0625(85)(49 - 46.85)]\ 2$$

$$= [3.44 + 3264 + 10.13 + 3533 + 3199 + 11.42]\ 2$$

$$= \underline{20.042} \text{ IN}^4$$

2.2 Static Moment At Neutral Axis (Box Structure).

$$Q = [\ 1.88(46.85-3.5) + \frac{0.0625}{2}\ (46.85-6.5)^2\ ]\ 2$$

$$= [81.50 + 50.88\}\ 2$$

$$= \underline{\underline{265}}\ IN^3$$